

Smart Systems Integration – Challenges for Micro/Nanotechnologies

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Autor
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Fraunhofer ENAS

Fraunhofer



Einrichtung
Elektronische
Nanosysteme

ZfM
Zentrum für
Mikrotechnologien



TECHNISCHE UNIVERSITÄT
CHEMNITZ

OUTLINE

1. Introduction TUC/ZfM und Fraunhofer ENAS

2. MEMS und Smart Systems Integration

3. Examples from ZfM/ENAS

- Micro mirrors
- Spectrometer
- Acceleration Sensors
- RFID label
- Wafer level and sensor packaging

4. Conclusion

The Fraunhofer-Gesellschaft in Germany

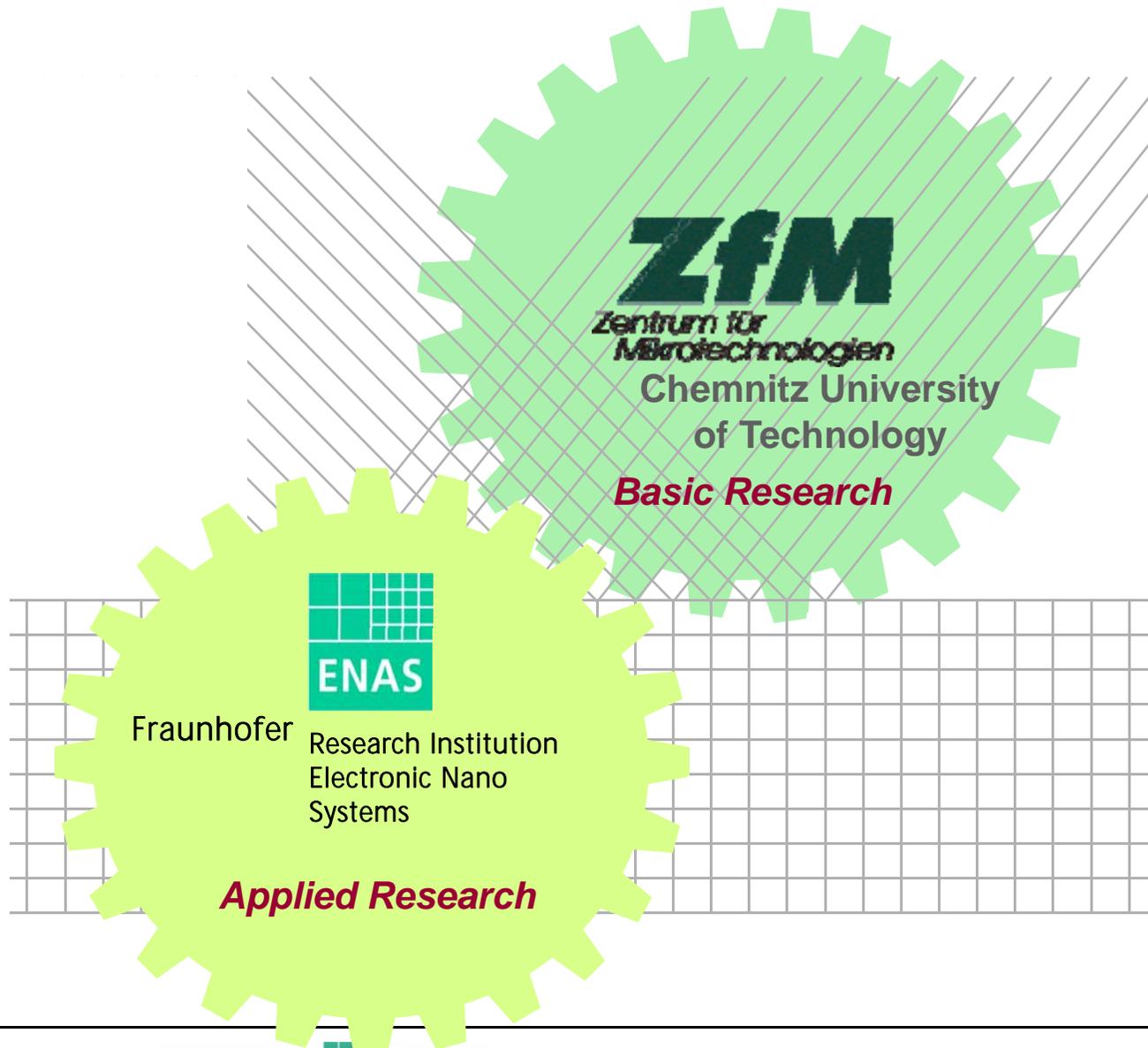
80 research units (56 Institutes)
at approx. 40 locations

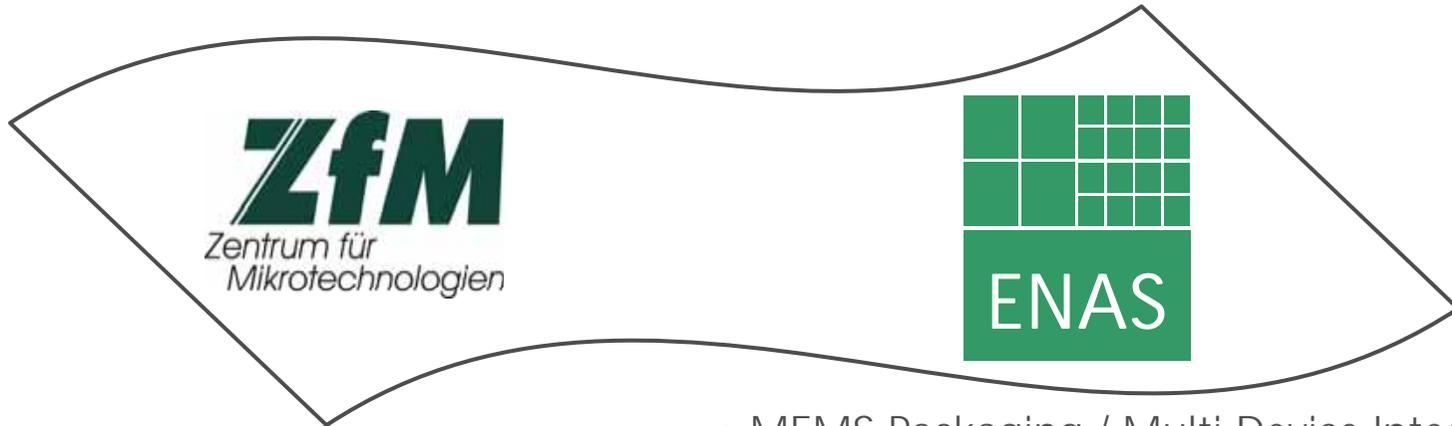
- Institutes
- Branches of Institutes, Research Institutions, Working Groups, Branch Labs and Application Centers



Our Story

- 1991-1993 Foundation of the Center for Microtechnologies (ZfM)
(2003 – 120 employees)
- 1995-1997 Complete reconstruction of the ZfM buildings
- 1998/1999 Foundation of the Department Micro Devices and Equipment (MDE) as Branchlab Chemnitz of Fraunhofer IZM Berlin
- 2002 Moving into new laboratories of the Fraunhofer IZM in the Fraunhofer IWU building with new equipment
- 2008 New buildings ZfM, Fraunhofer IZM, Institute of Physics
- 2008 **Fraunhofer ENAS**





Fraunhofer
ENAS

- MEMS Packaging / Multi Device Integration
- System Integration / BEOL
- Reliability
- Printed Functionalities
- Advanced System Engineering

ZfM

- Basic research focus on nano materials and technology
- Design of systems and components
- Basic processes for demonstrators (sensors, actors, arrays, BEOL)

Equipment and service offers

- ZfM facilities include 1000m² of clean rooms
- 300m² clean room class 10
- processing of 100mm, 150mm and 200mm wafers



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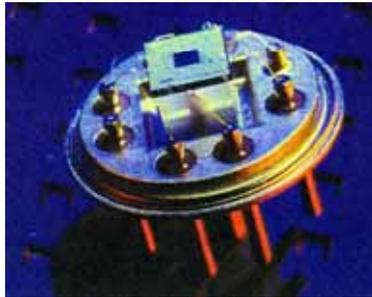
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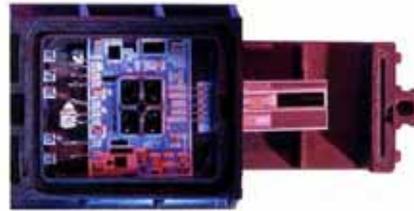
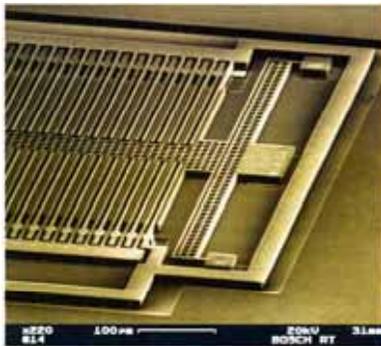
Commercialized MEMS in Automotive Applications

Robert Bosch GmbH

Reutlingen



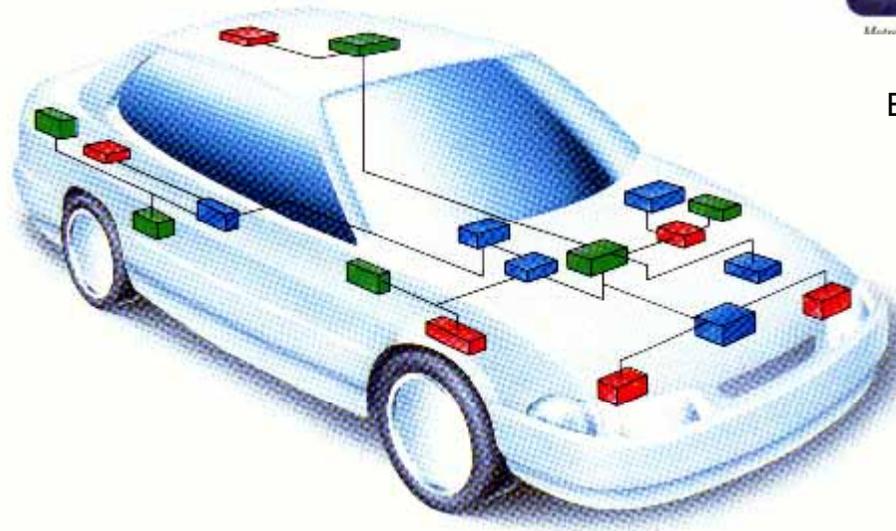
Pressure sensors for air pressure, intake pressure, combustion chamber pressure



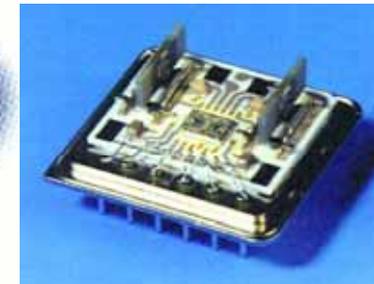
Hot-film air flow sensor



Electronic motor control

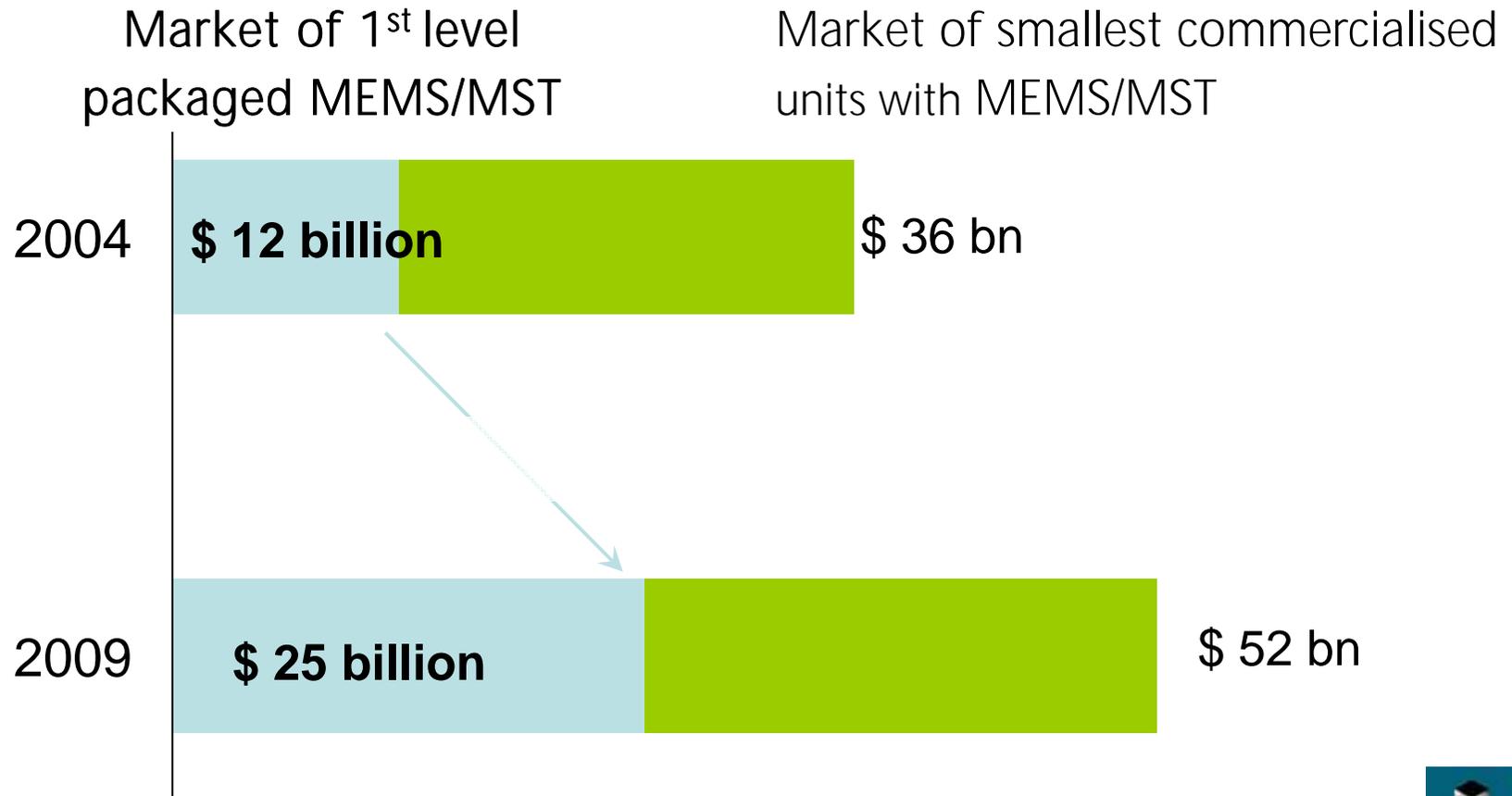


Surface micromechanics for angular rate sensors and acceleration sensors



Piezoelectric airbag sensor

Total market for MEMS/MST in 2004 and 2009

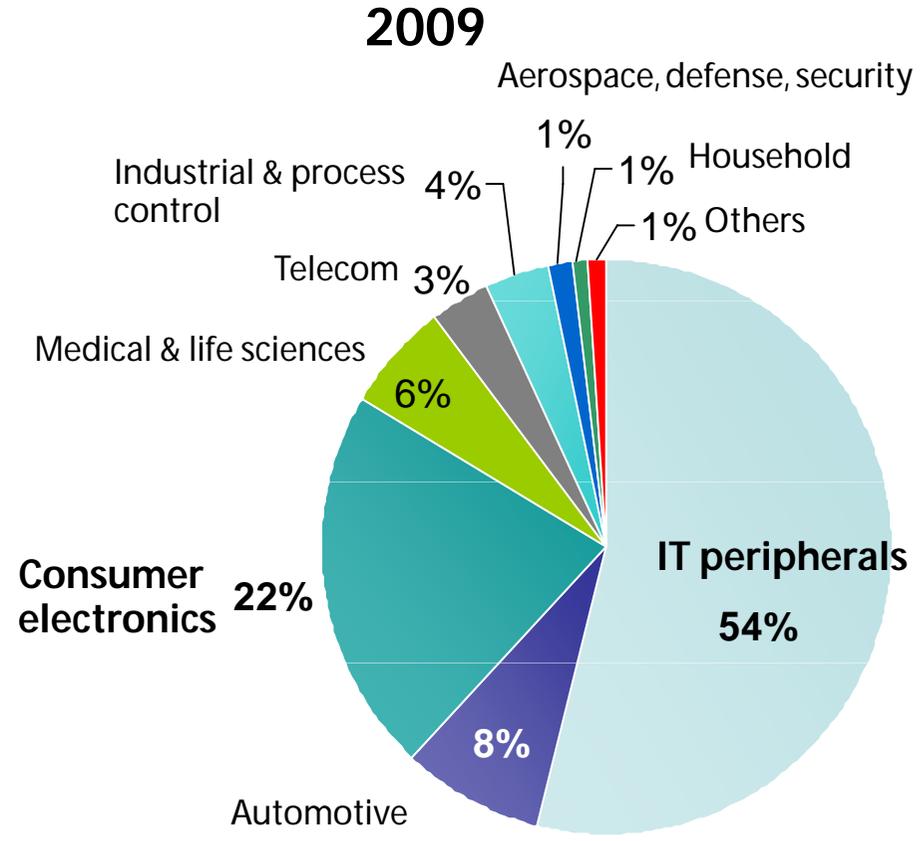
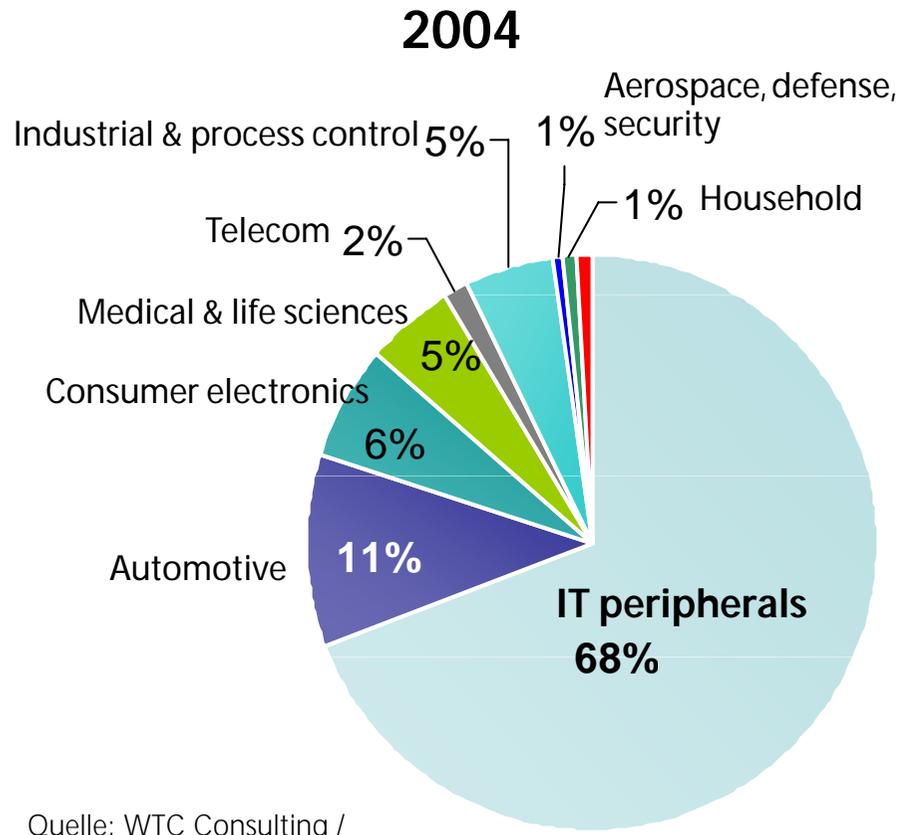


Quelle: WTC Consulting / Nexus 2005-2009

Source:



IT peripherals remain the main application fields in 2004 & 2009



Quelle: WTC Consulting /
Nexus 2005-2009

(total \$12 billions)

(total \$25 billions)

The 3 drivers for MEMS in consumer electronics

Large screens: High Definition Television for everybody

- Rear Projection TV and front projection TV (home theater)
- 6.5m units in 2005 to 12m units in 2009 for projection TV (iSuppli Corp.)



More storage in digital equipment

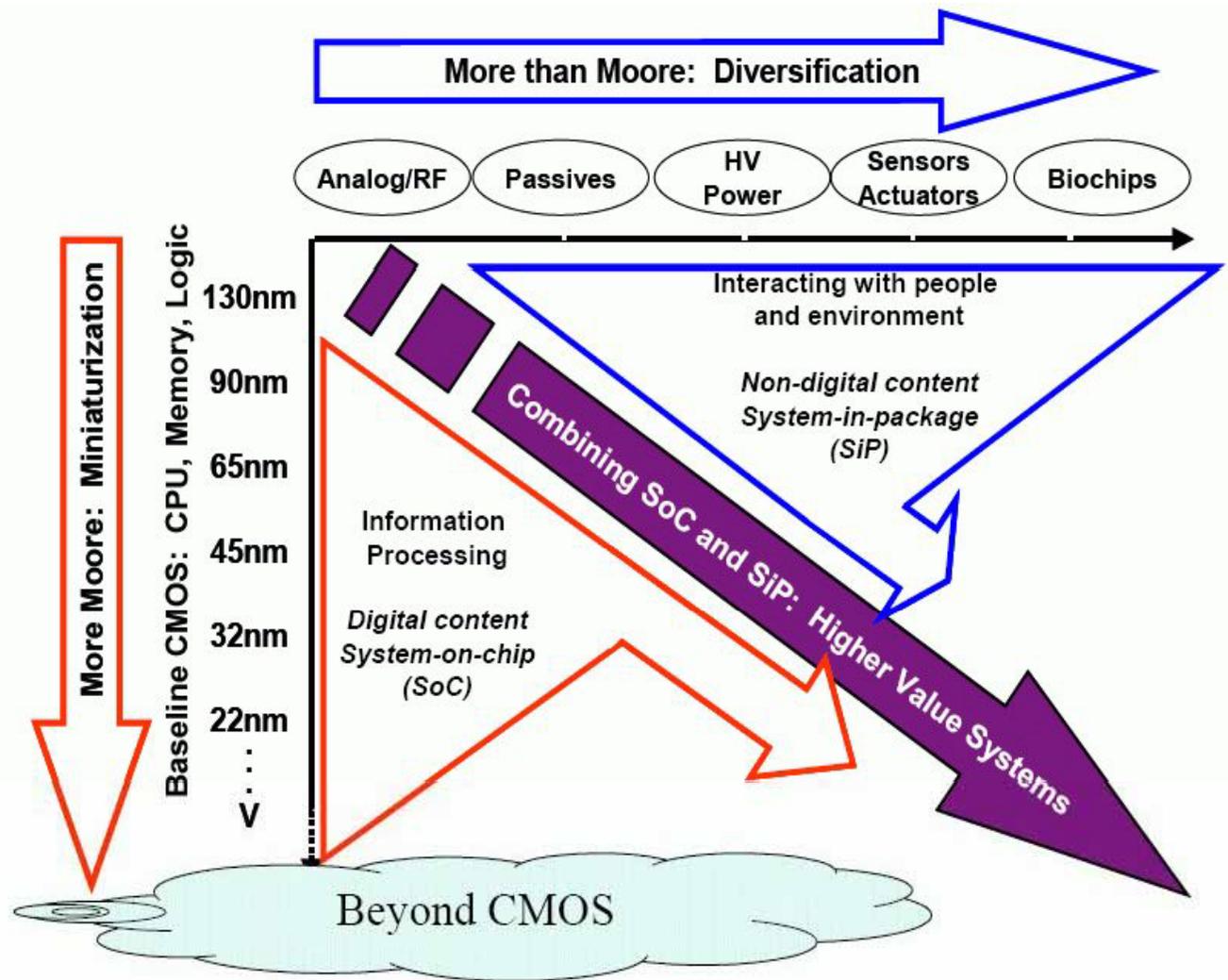
- HDD enter digital video cameras, music players, smart phones, set top players, DVD recorders
- 11m units in 2004 to 200m units in 2009



Mobile handset...you can also phone with it

- MEMS accelerometers since Sep. 2003 (NTT Docomo)
- Next: gyroscopes, MEMS display, micro fuel cell, MEMS fingerprint, motors for camera zoom, gas sensors, pressure sensors

Quelle: WTC Consulting / Nexus 2005-2009



Future Challenges

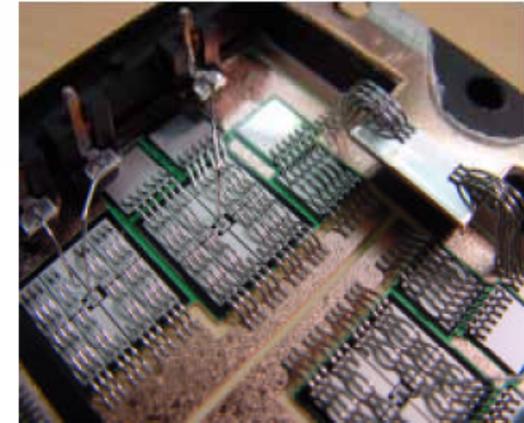
Nanotechnologies and Devices

Smart Systems Integration

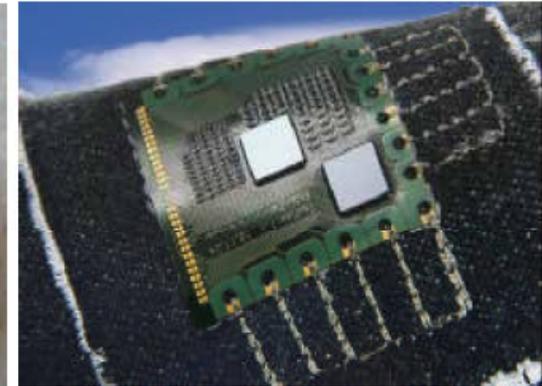
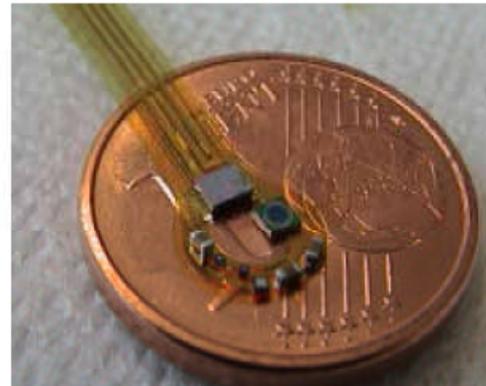
Definition Smart Systems Integration

Integration of Different Functionalities

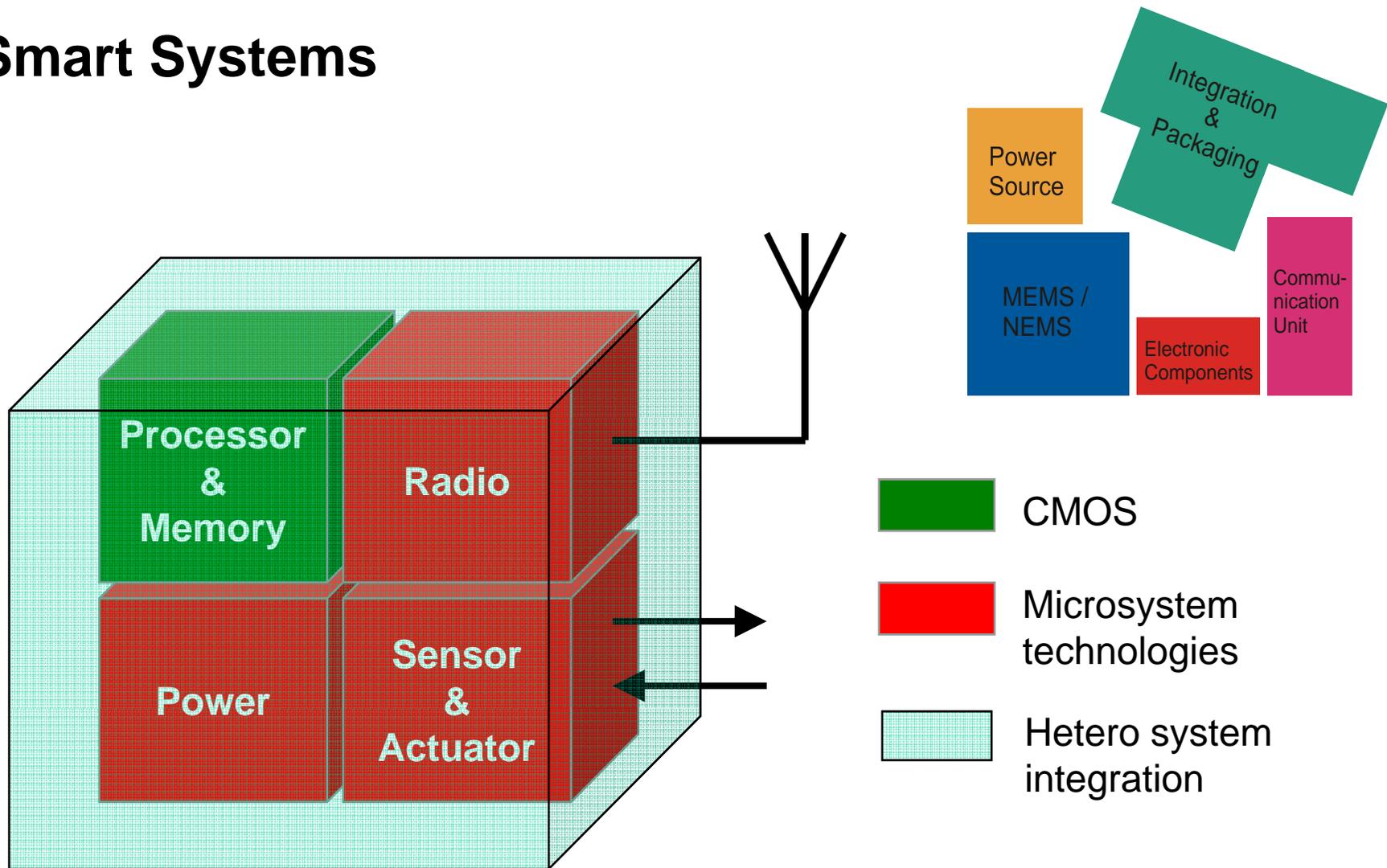
such as Signal Processing, Sensors, Actuators, Photonics, Power, Coolers with a High Degree of Miniaturisation and Flexibility to Reasonable Costs



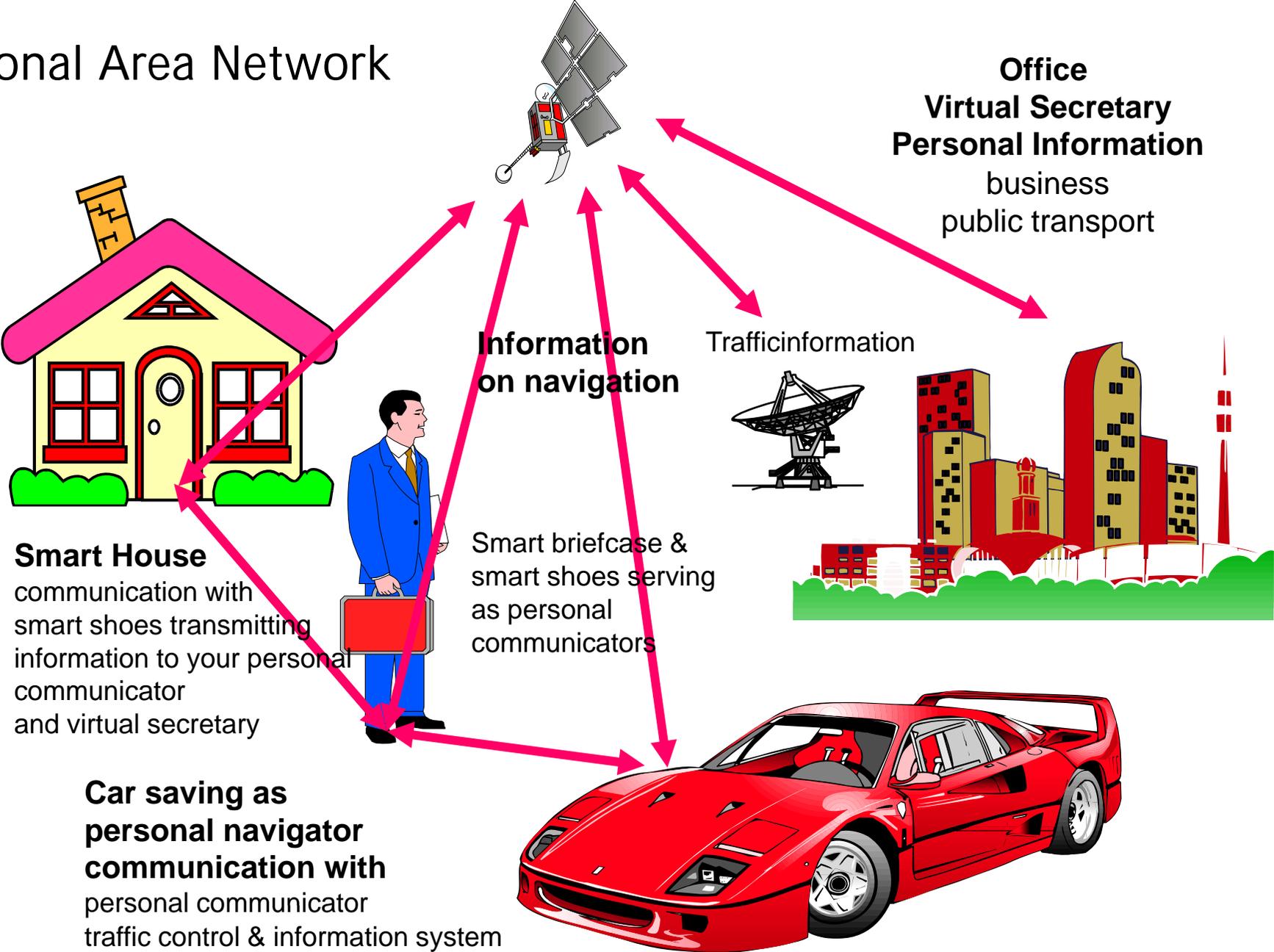
in one Unit (e.g. Package), that bridges the Gap between Nano-Electronics and Applicationbis adopted to the application environments



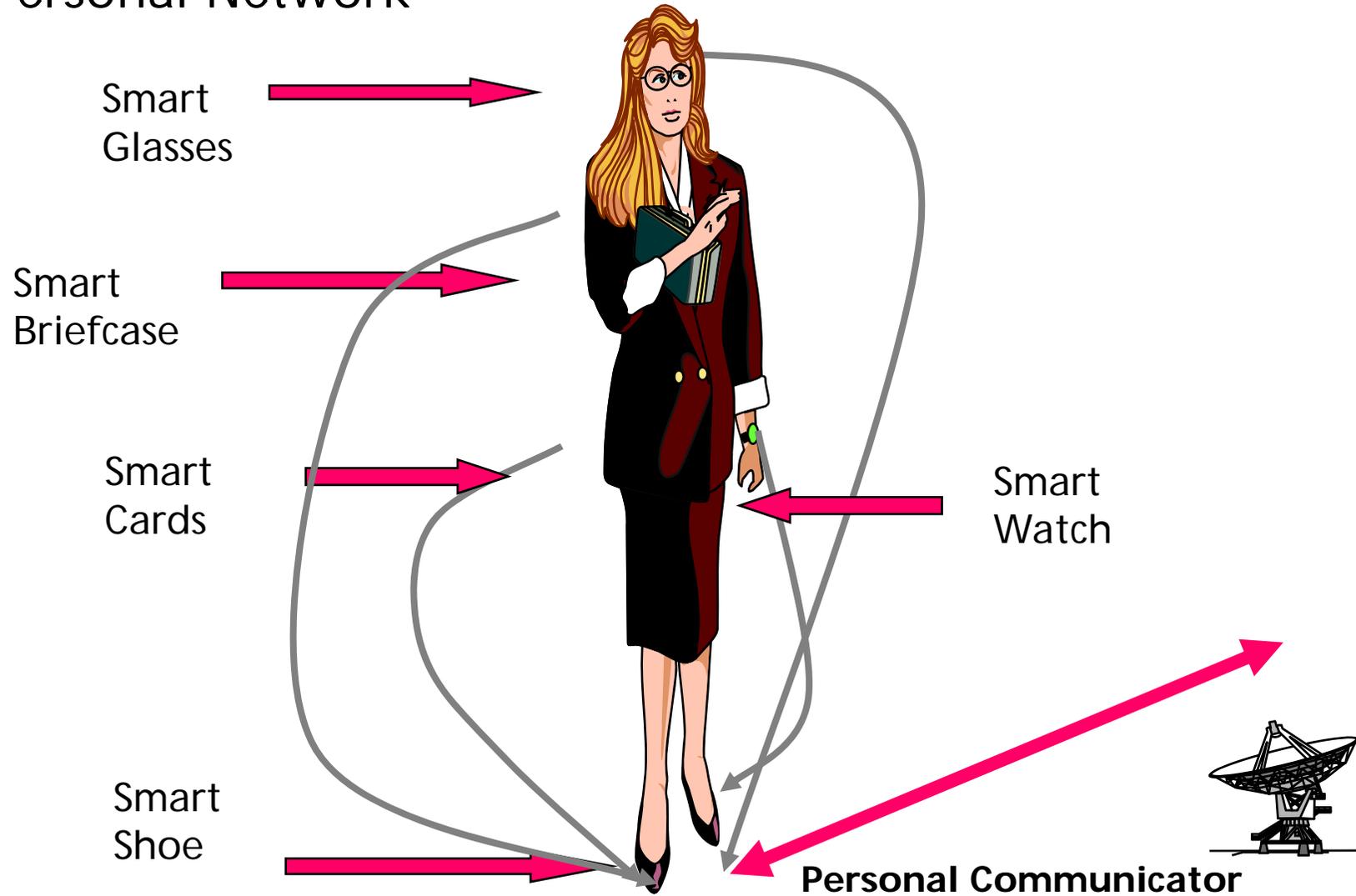
Smart Systems

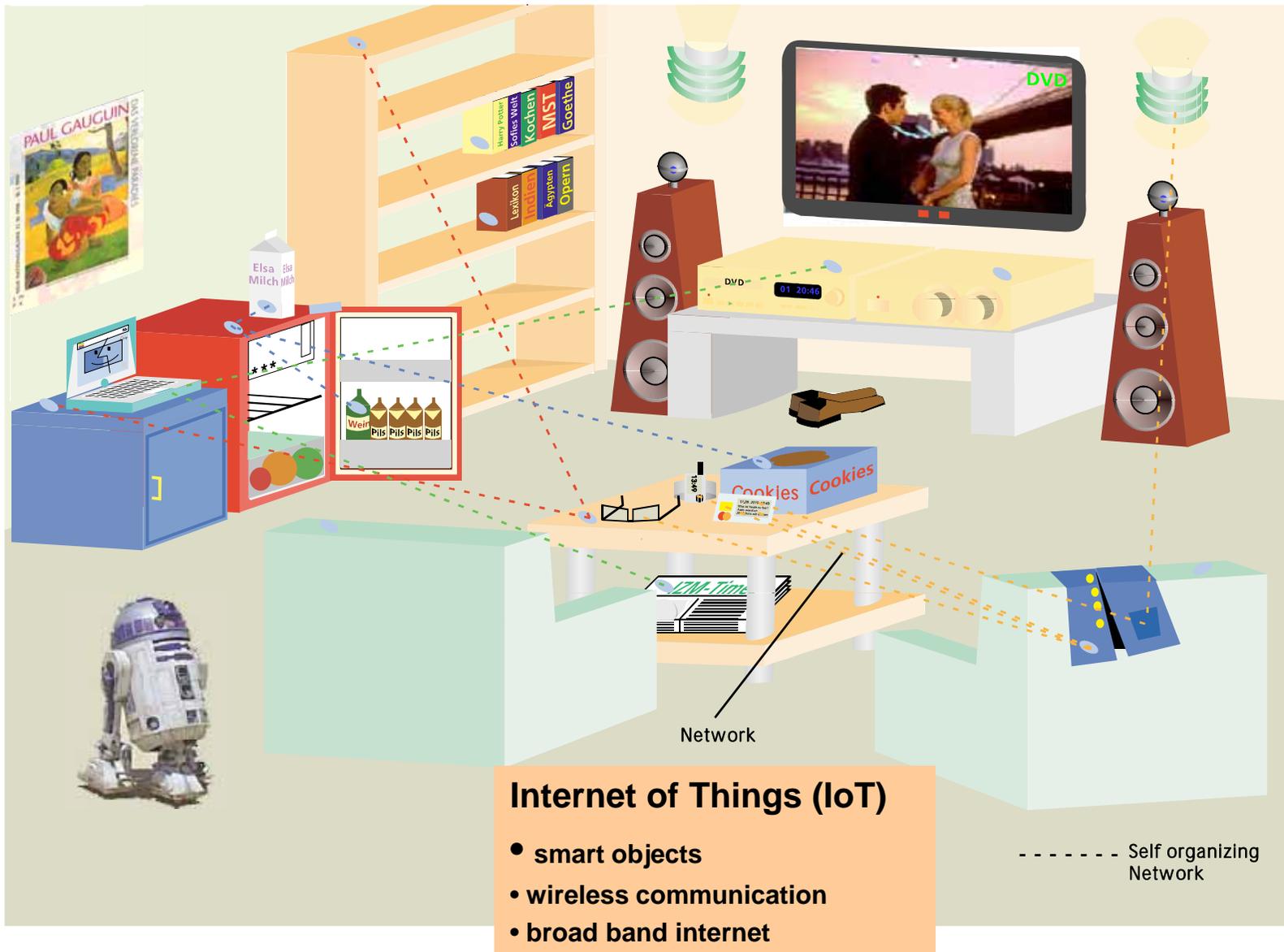


Personal Area Network



Local Personal Network





Internet of Things Application Example



Station

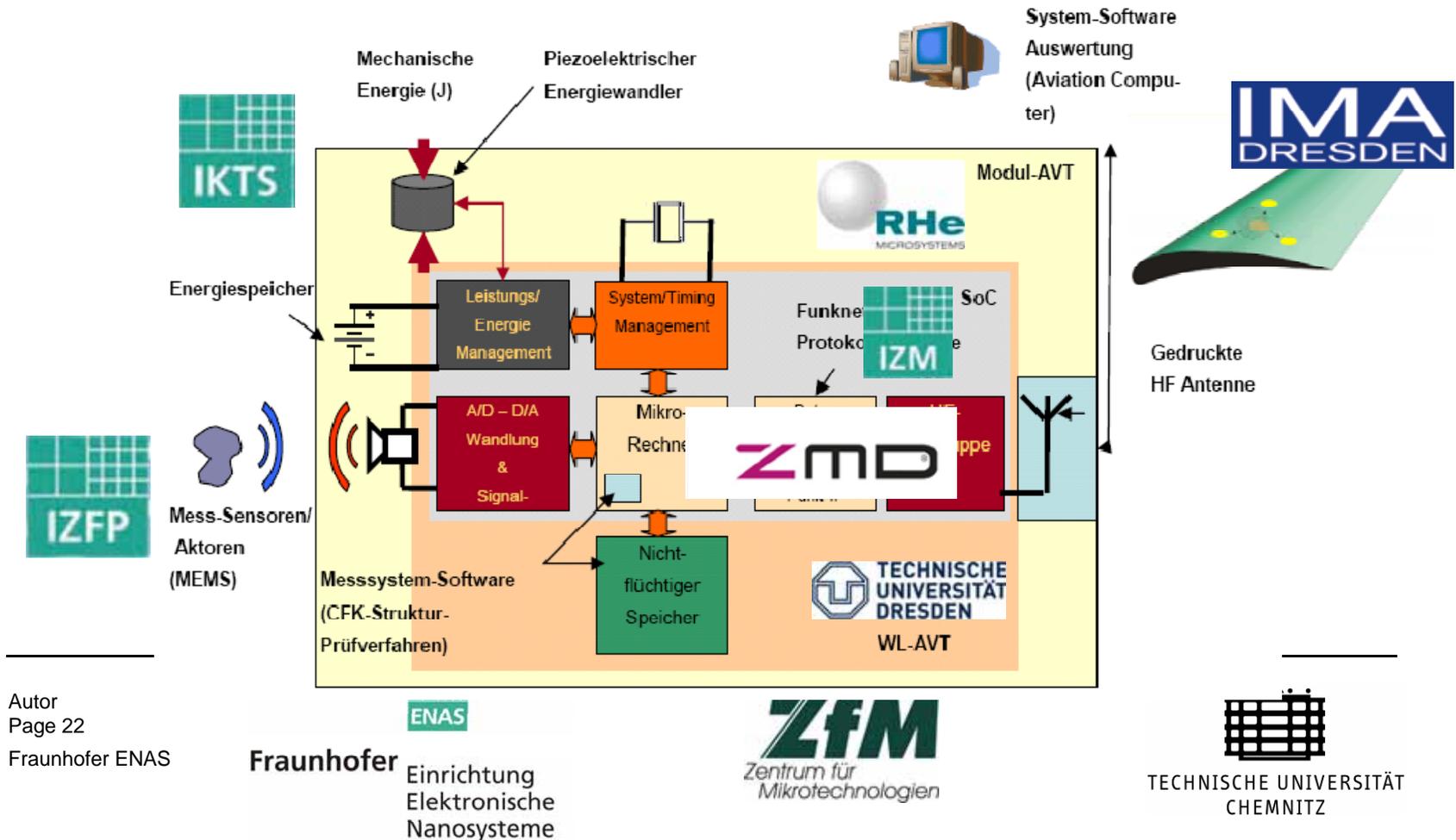


Service station



Leitprojekt 3 Cool Silicon

Kabellose Sensoren für die Strukturüberwachung

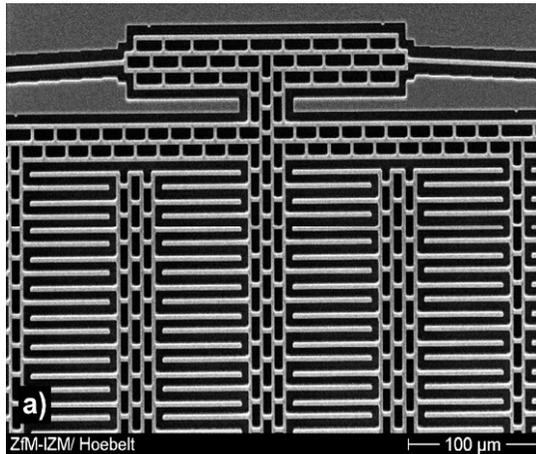


Trends

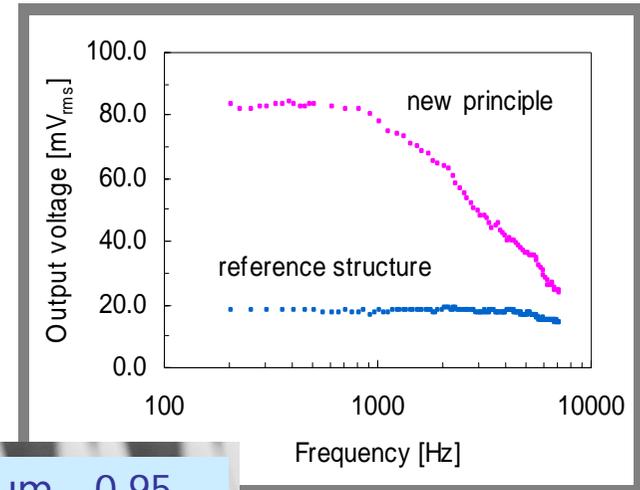
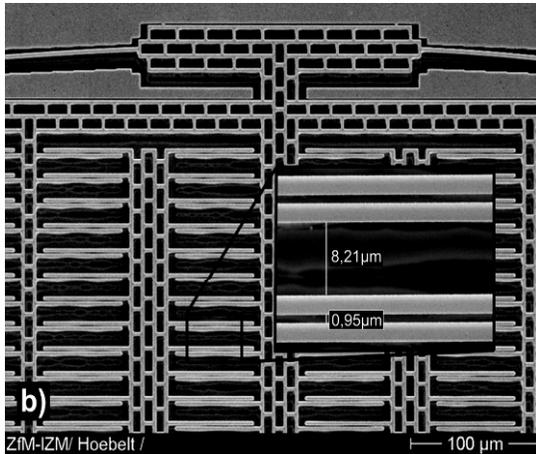
MEMS / Nanointegration
→ NEMS

In-Process Sensing Gap Reduction of Capacitive Transducers

before -



after
displacing



Gap width down to < 100 nm for increased sensitivity of shrinking devices

Trends

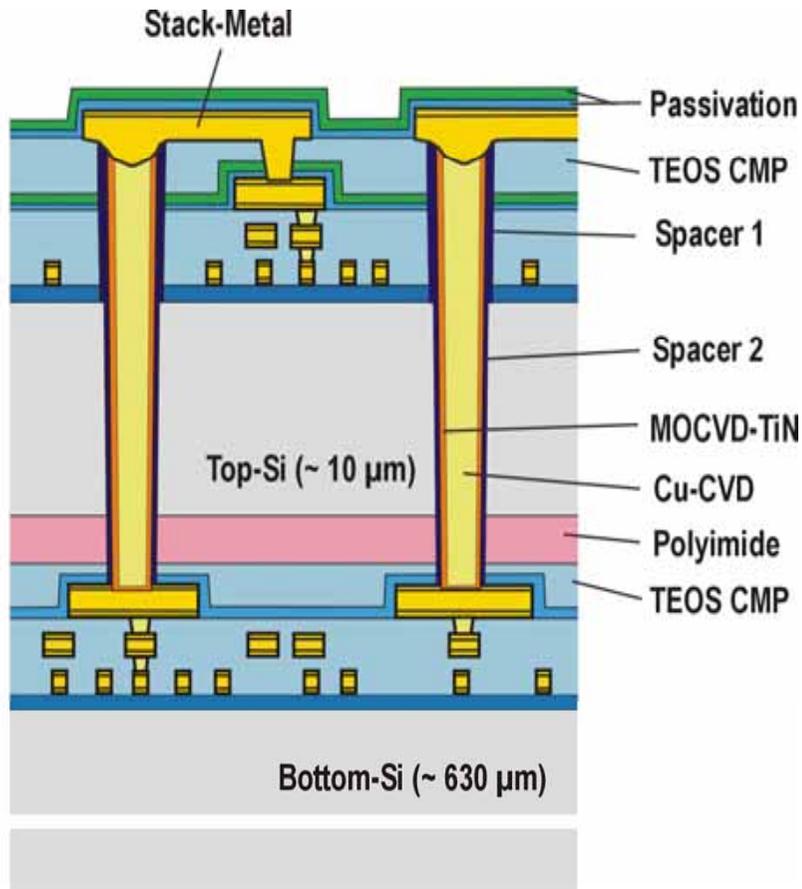
MEMS / Nanointegration

→ NEMS

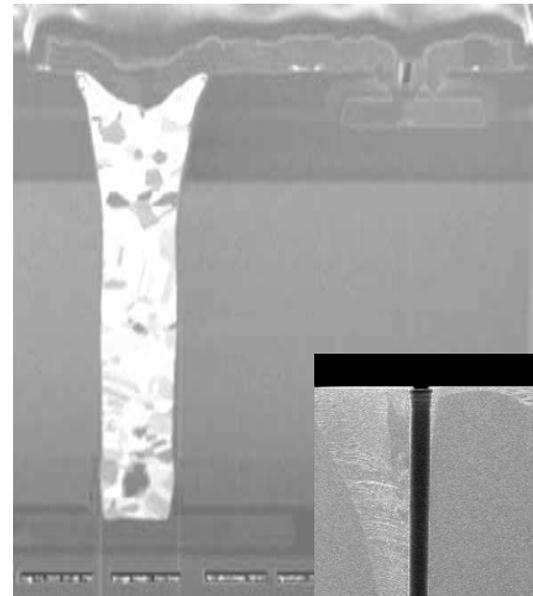
MEMS / Semiconductor Integration

→ SiP

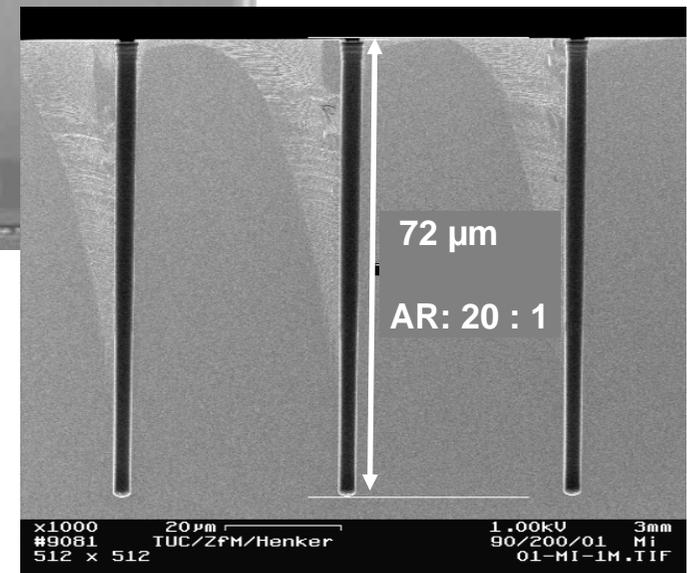
3D Wafer-to-Wafer or Chip-to-Wafer Technologies



Schematic of ICV technology (FhG IZM Munich)



Through Si Via (TSV) Technology with **CVD-Cu** or ECD Cu



High aspect ratio Si etching

Trends

MEMS / Nanointegration

→ NEMS

MEMS / Semiconductor Integration

→ SiP

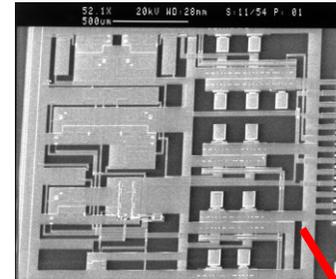
Multiple MEMS Integration

→ multi device

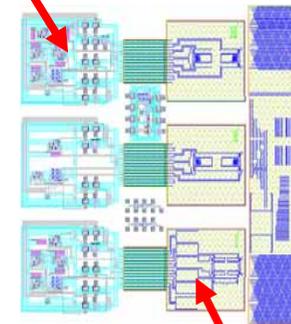
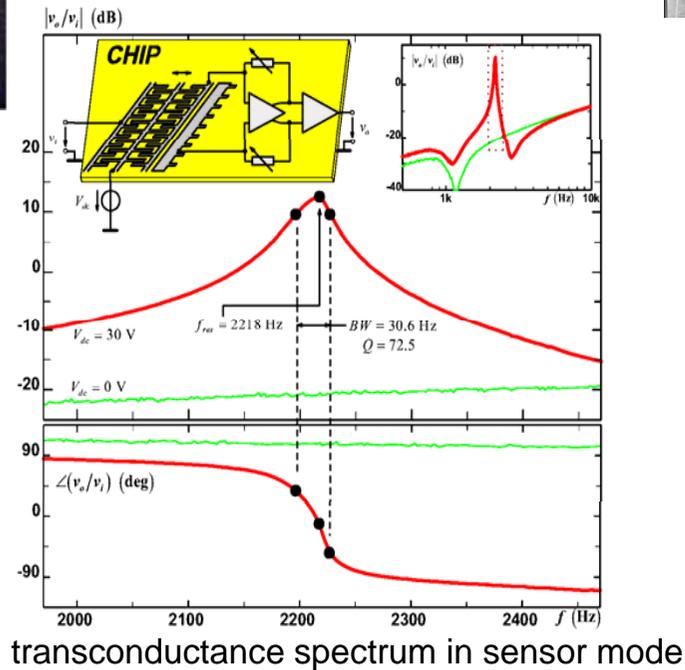
SOC for Noise Reduction: Integrated Vibration Sensor / Resonator



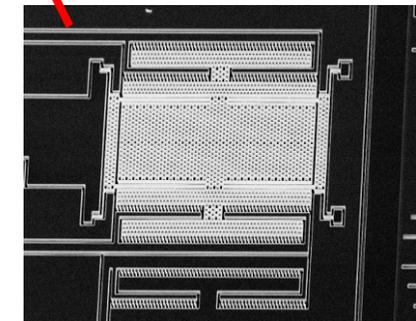
SOC in standard package



CMOS on-chip readout amplifier including self-excitation for oscillator mode (fabricated by ZMD)



layout



SCS resonator: ENAS/
ZfM **post CMOS**
process

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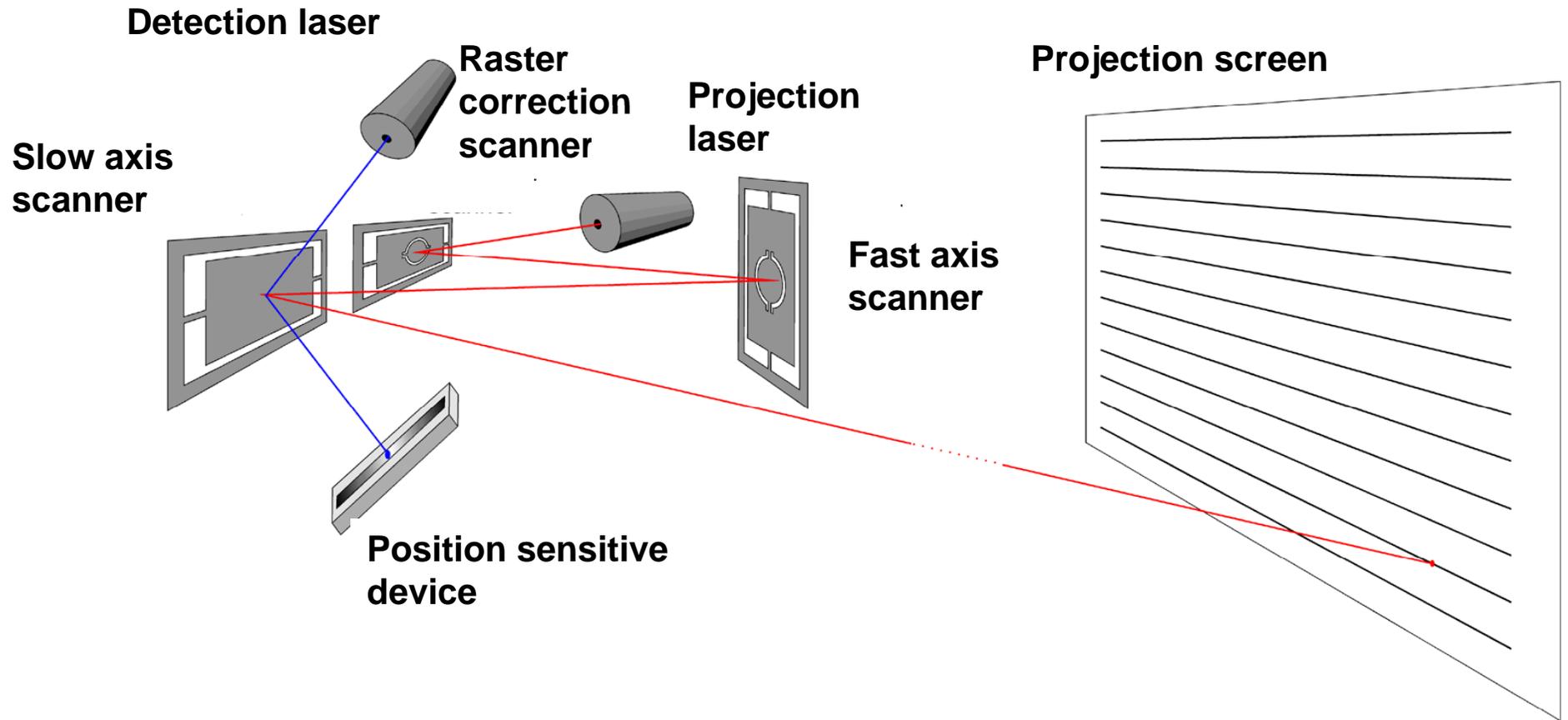
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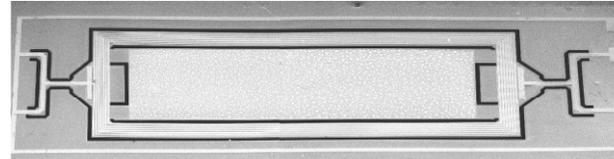
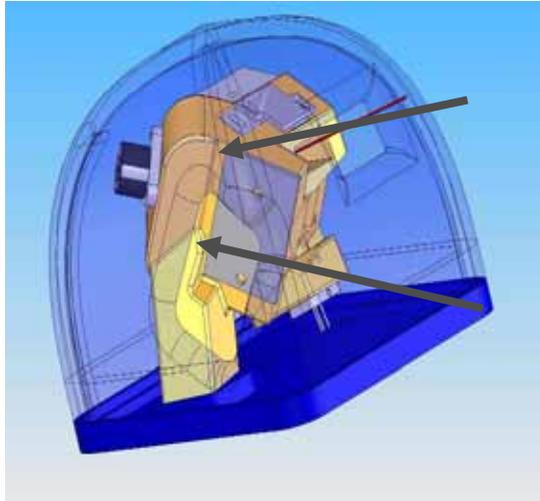
4. Conclusion

Laser Display with Si micro mirrors

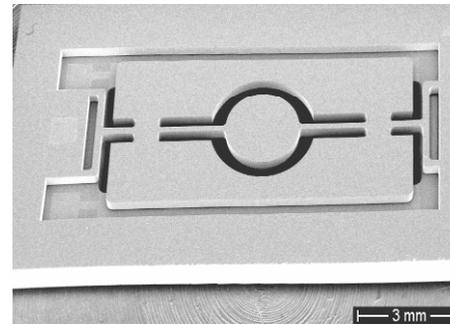


Scannersystem for Head Up Display

Demonstration system



Slow axis magnetic scanner



Fast axis electrostatic scanner

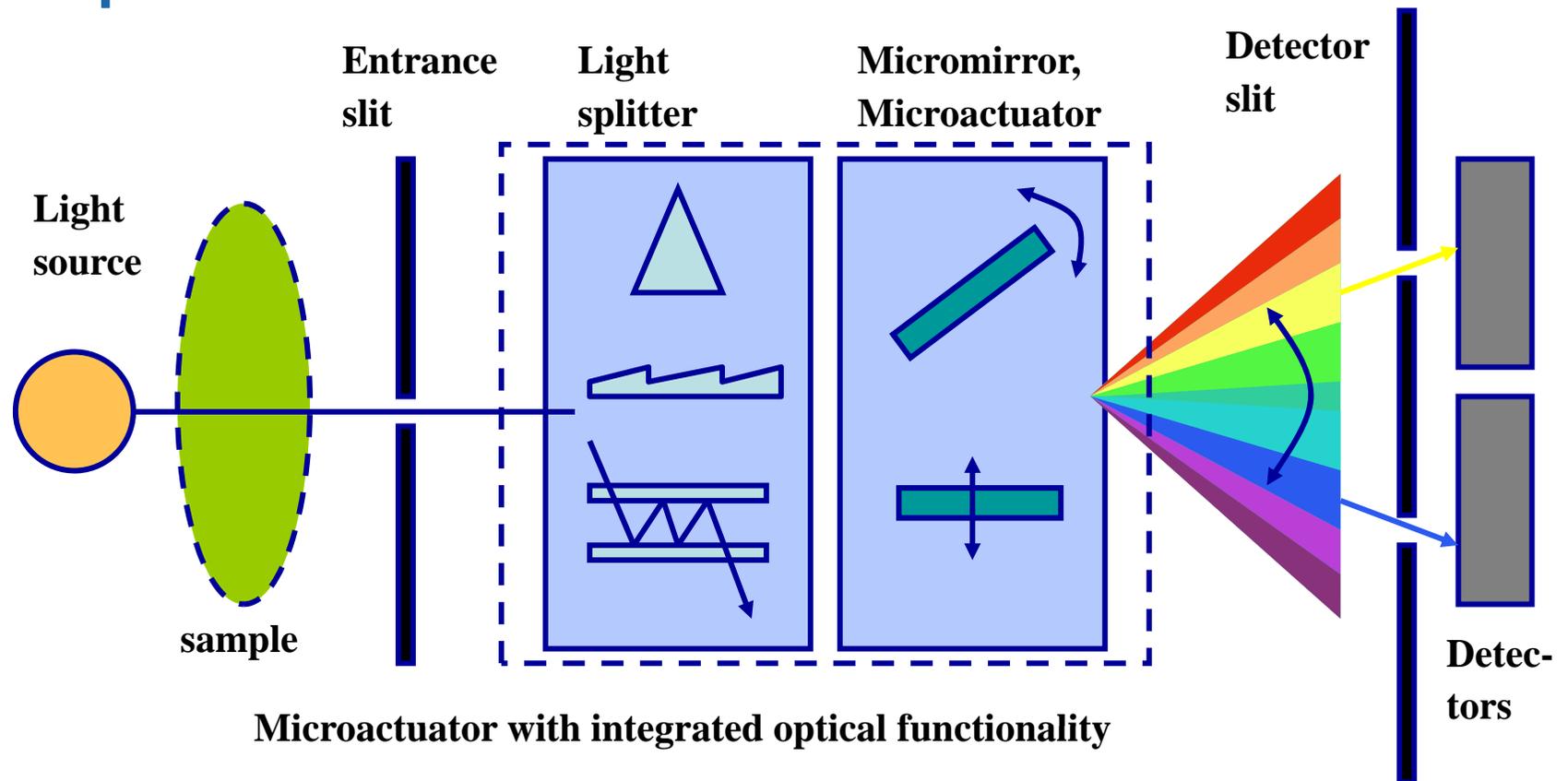
Test image



Results

- Laser projection display for images from PC graphics adapter
- Resolution 1024x768 (XGA)
- Scan angle 10°
- Integrated scanner driving electronics

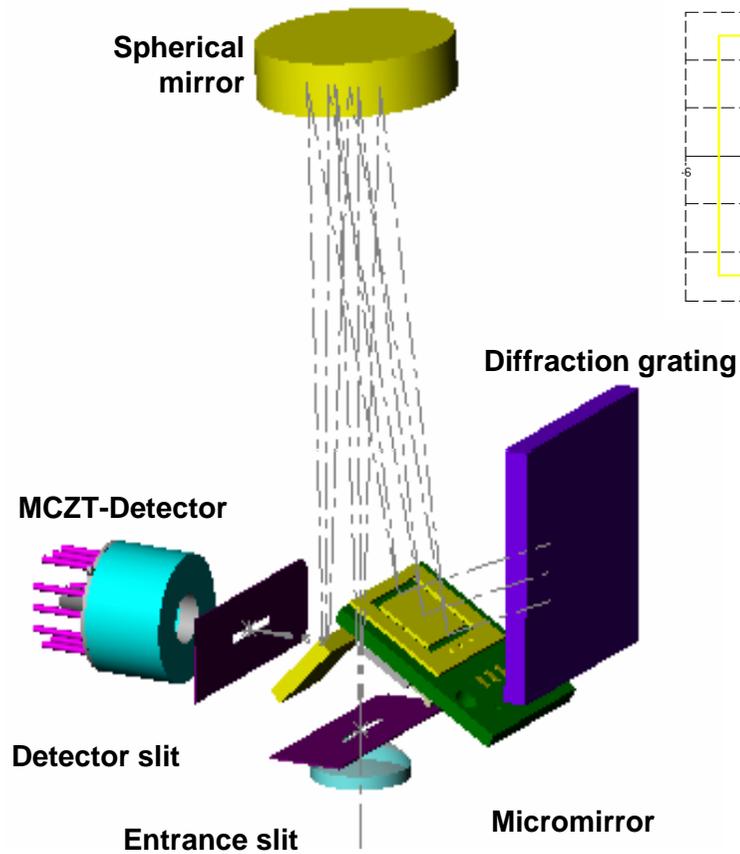
Micro spectrometer - Scheme



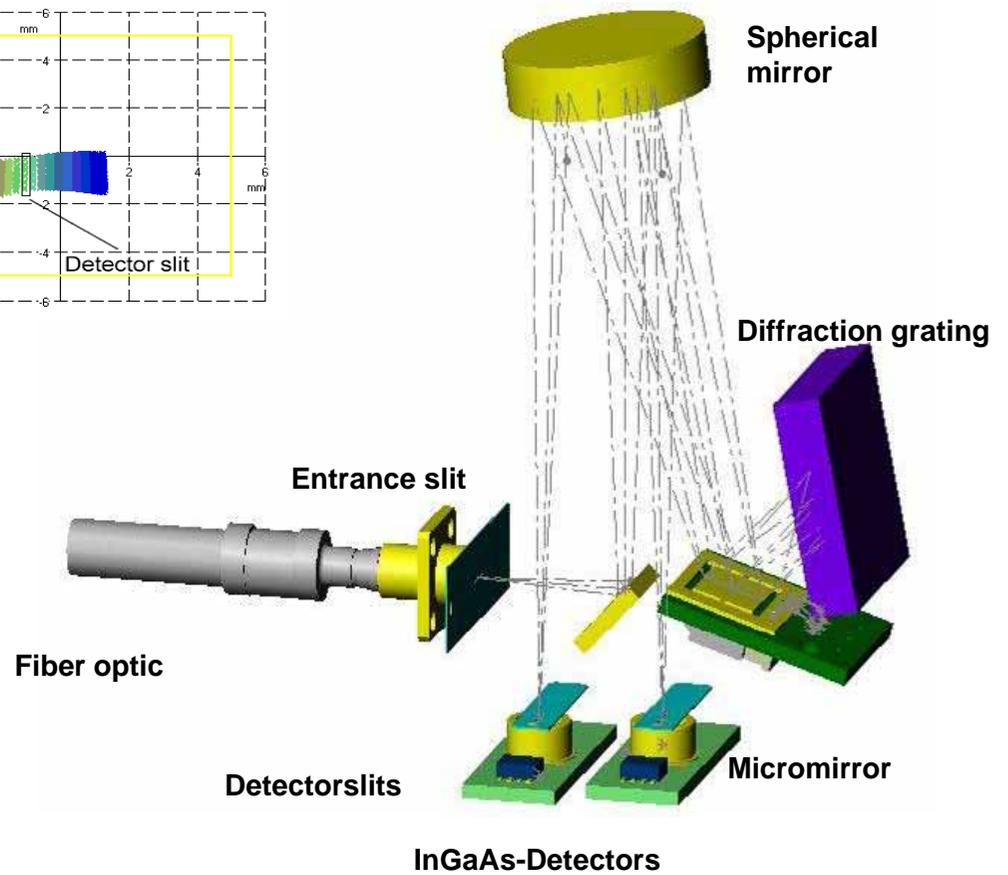
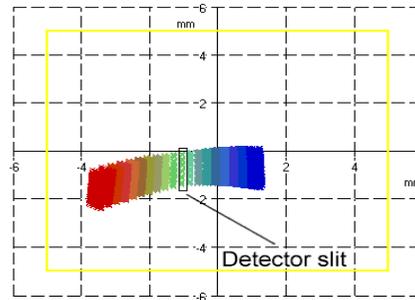
- Spectrum of light source modified by sample (characteristic absorption)
- Spectrum splittet with respect to time and/or local position
- (one) detector receives different spectral portions at different times

Optical Setup & Functional Principle

MIR-Spectrometer



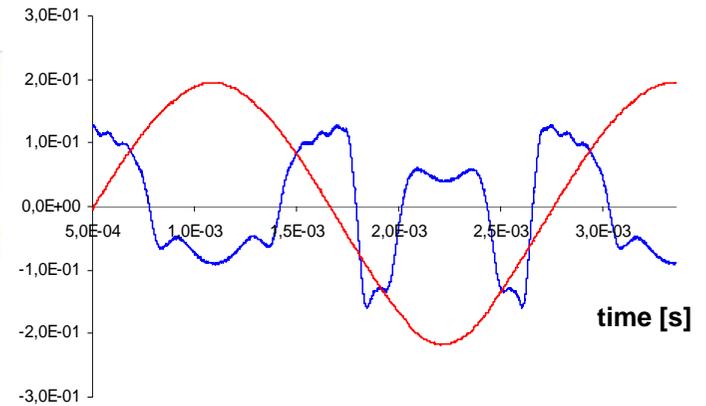
NIR-Spectrometer



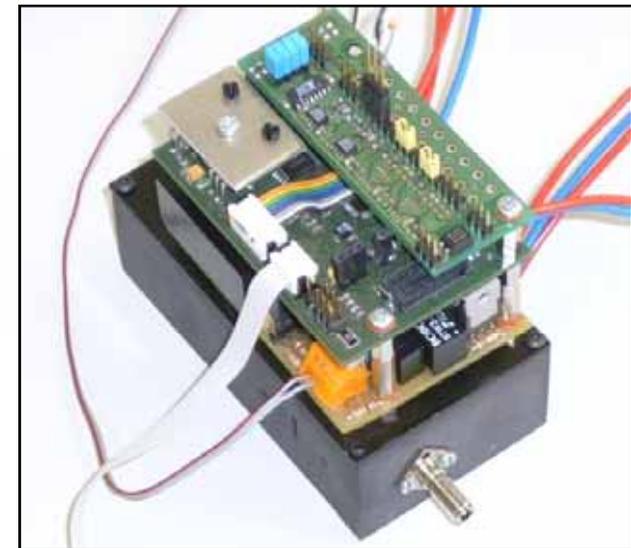
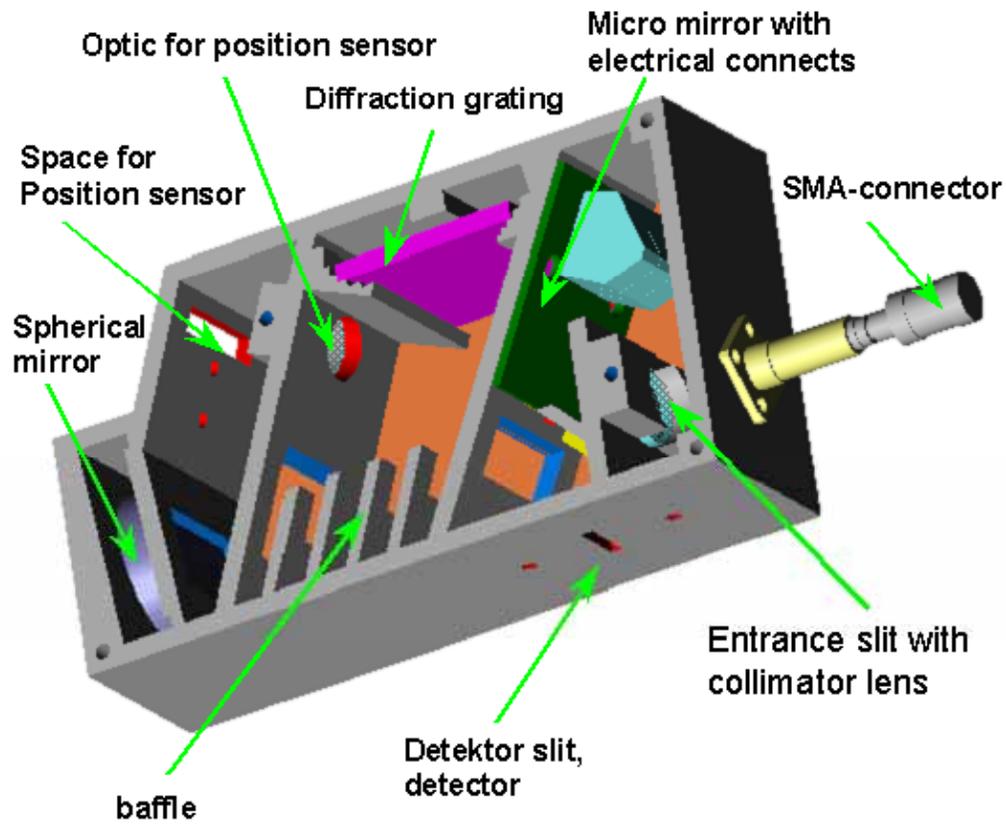
Micro mirror spectrometer – Packaging and Experimentals

Monolithic Package

- small adjustment tolerances
- high vibration stability



Spectral transmission measurement of a polystyrol sample
every half period corresponds to a specific wavelength range



Spectrometer with control unit

Environmental Applications

- A variety of environmental problems now affect our entire world
- As globalization continues local problems will be transformed into international issues

Problems

- Global Warming
- Hazardous Waste
- Acid Rain and Smog
- Air and Water pollution
- Population Growth
- Conversion of forest land for agriculture



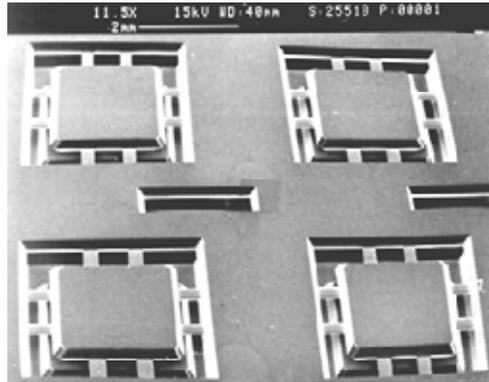
Other applications

- Anesthesia Monitor
- Fire & Flame Detection
- Inline CO2 Measurement in beverage

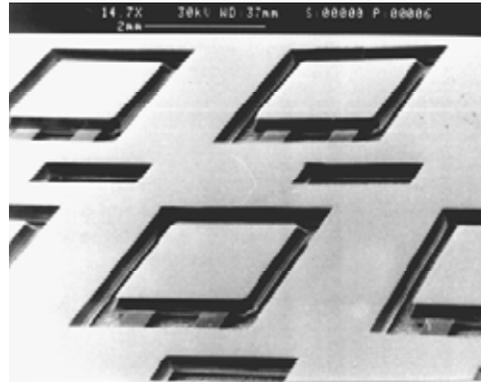
➔ Information technology, communications and sensing are enabling technologies

➔ **Environmental control by using MEMS-spectrometers**

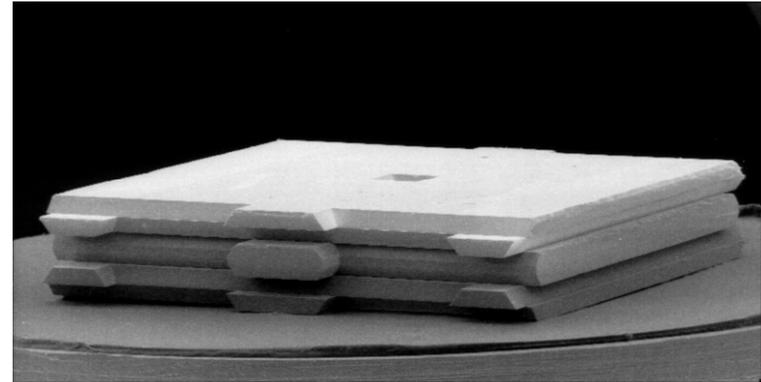
Fraunhofer ENAS best practice using bulk micromachining



Sensor mass with eight springs



Sensor mass with two springs



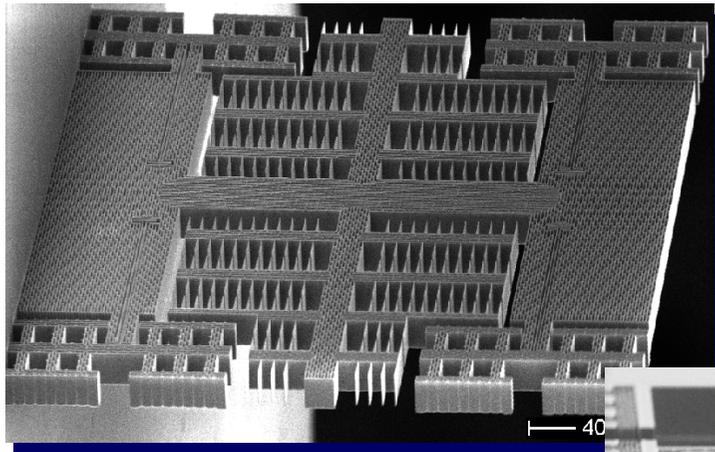
Packaged acceleration sensor



LCR-93 FA. LITEF:
Attitude and Heading
Reference System
(three fiber-optical gyros,
three micromechanical
acceleration sensors)

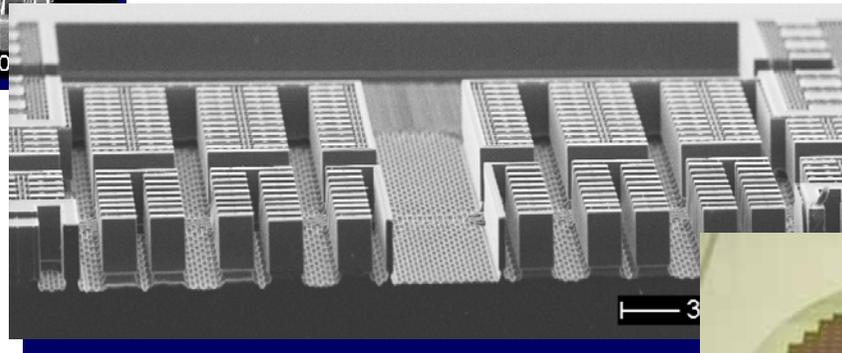


AIM7E– SEM of Seismic Mass and Counter Part using surface micromachining

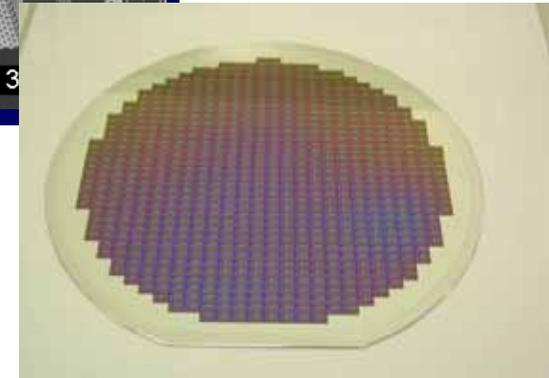


seismic mass

electrodes ...

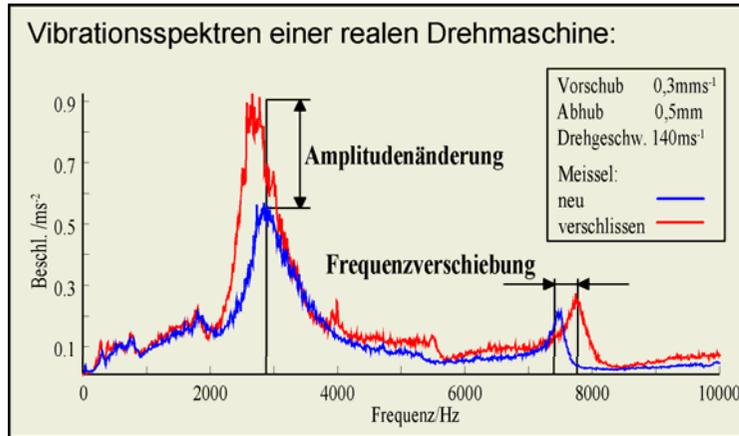


Complete sensor



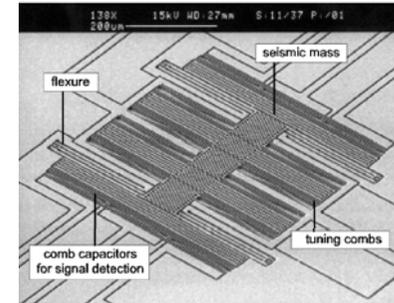
Multi Device Integration - Systems & Design

- *MEMS-Development (Inertial Sensors, Microfluidic)*
- *System Integration (Head-up Displays, miniaturised Spectrometer)*
- *Measurement Technique (System Test, Wafer level Test, Chip Test)*
- *Component and System Design*
- *Method and Tool Development for Modelling & Simulation*

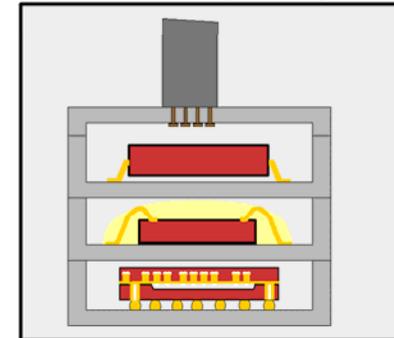


Vibration spectra of a real lathe

MEMS device:



System in the package:



Application



TECHNISCHE UNIVERSITÄT CHEMNITZ

AIM low g Sensor System Prototypes Fabricated



CLCC44

AIM7 sensor with
IMD 9801 ASIC

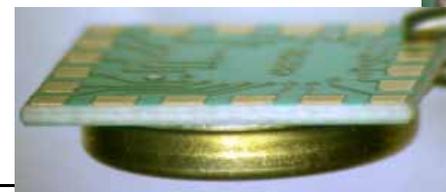


AIM7E sensor with M777.04 ASIC (ELMOS)



PLCC44

AIM5 sensor with AD7746 (24 Bit)
> evaluation by HL Planar



AIM5I sensor with CVC
ASIC (GEMAC)



Industrial Application



**Have every time
a
firm and save
foothold**

(tilt and position monitoring)

**High Precision
Inclination Sensors**



RFID Applications

Material Tracing



Box Management



Facility Management



RFID Application with Complex Additional Functions

- Detection of temperature - acceleration – pressure- light
- Combination of display and RFID
- Data processing and storage partly on the label

Smart Object / Item Technologies

Characteristics:

- intensive usage of MEMS technologies
- positioning in sensor networks
- positioning via antenna arrays
- distributed sensor networks
- external sensors
- bi-directional communication
- new battery concepts for active systems
- wireless sensor networks

Project ASIL: Active Smart ID Label

BMBF collaborative project: priority topic of the Microsystems framework programme:
Microsystems Technology for Smart Label Applications in Logistics

Objective: development of an active radio frequency identification (RFID) label for the monitoring of shock, inclination and temperature during transportation processes

Partner: KSW Microtec AG
ELMOS Semiconductor AG
Schenker AG
Memsfab GmbH
TUC-ZfM/ FHG-IZM

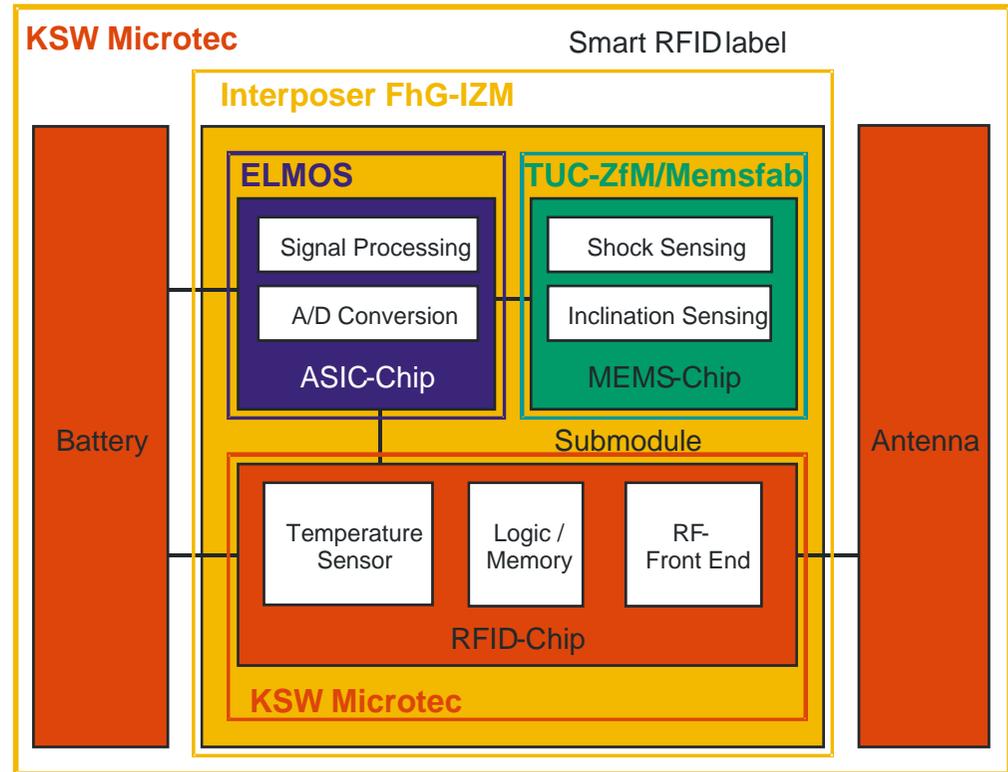


Project ASIL- RFID label concept

The label components:

- RF-chip with antenna
- battery for energy supply
- sensor system consisting of the micromechanical transducer and the signal processing electronic

The system has to detect and record inclination and mechanical shock. In order to reduce the complexity of the system, it is reasonable to measure both with the same microstructure

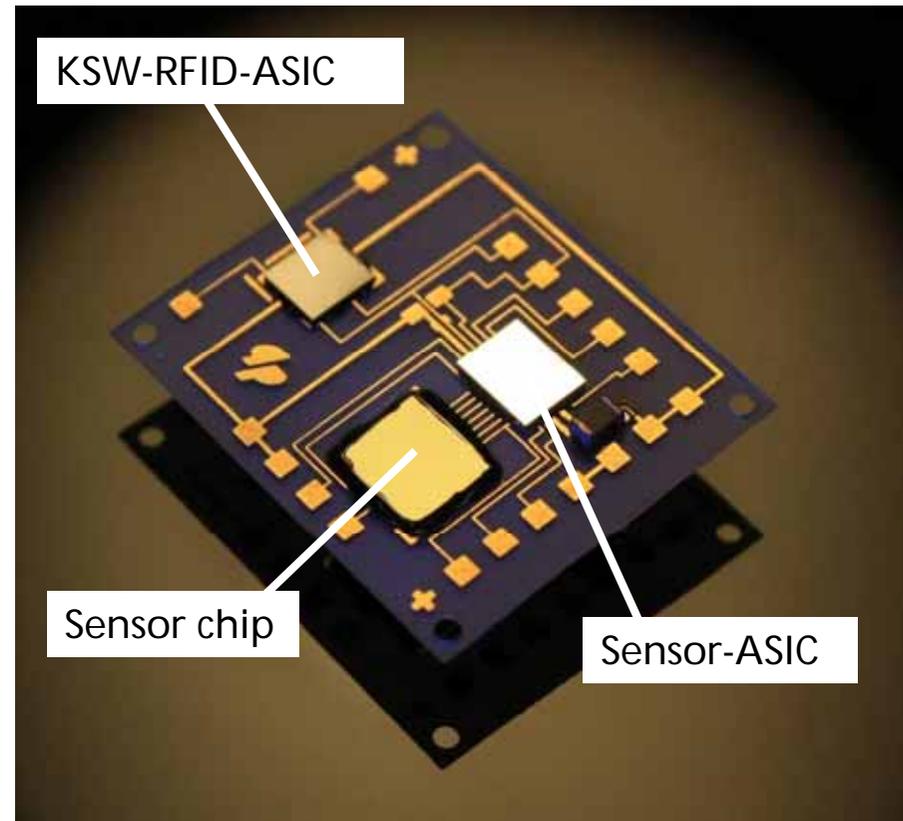
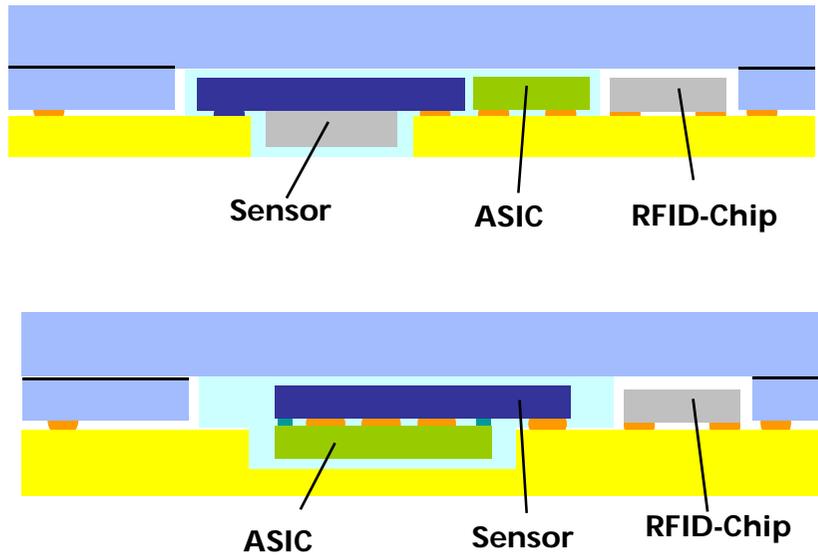


Specific requirements for the sensor system:

- low energy consumption
- high signal to noise ratio
- high temperature stability
- low device / sensor thickness

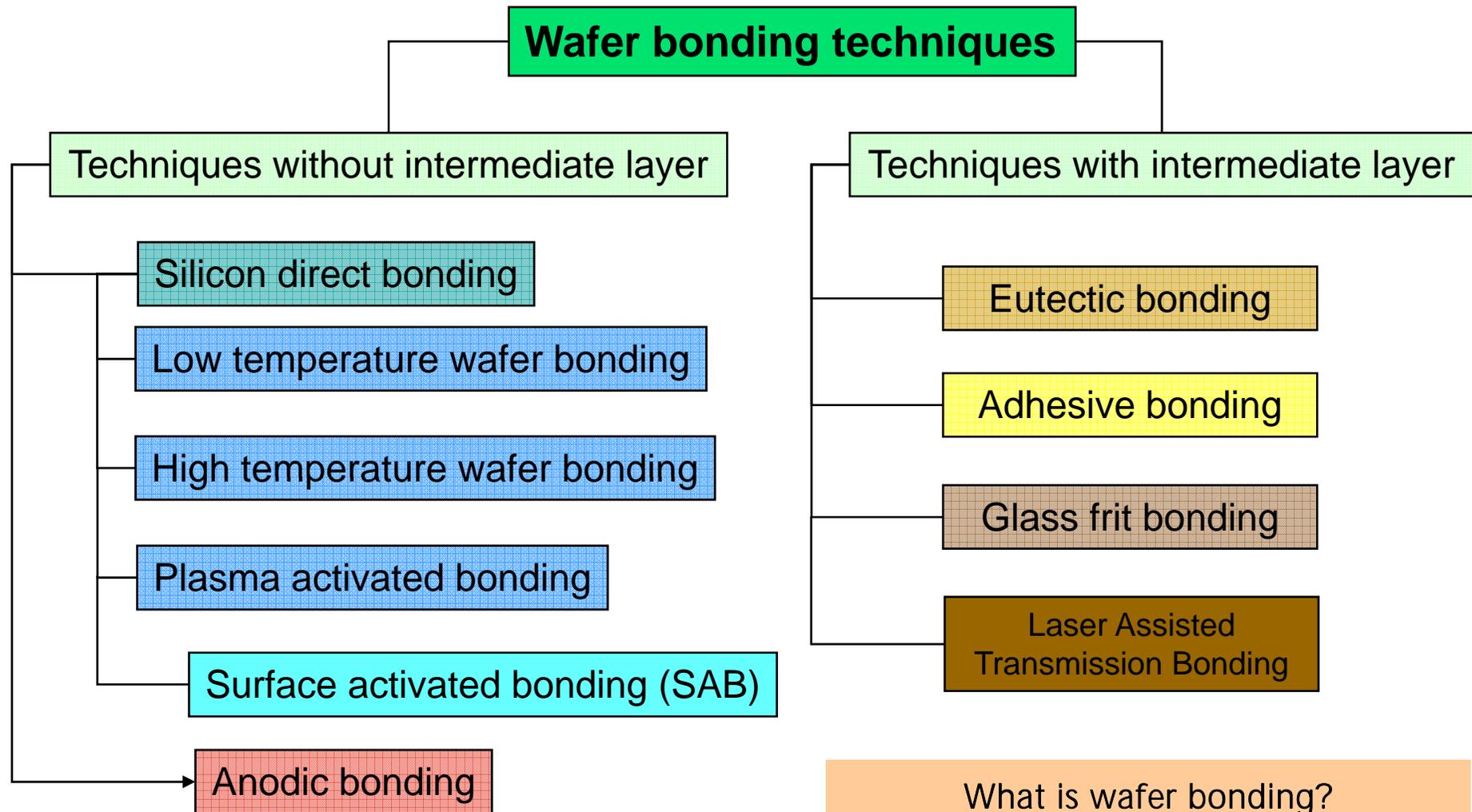
Projekt ASIL: Interposer and packaging fabrication

Packaging – Concepts



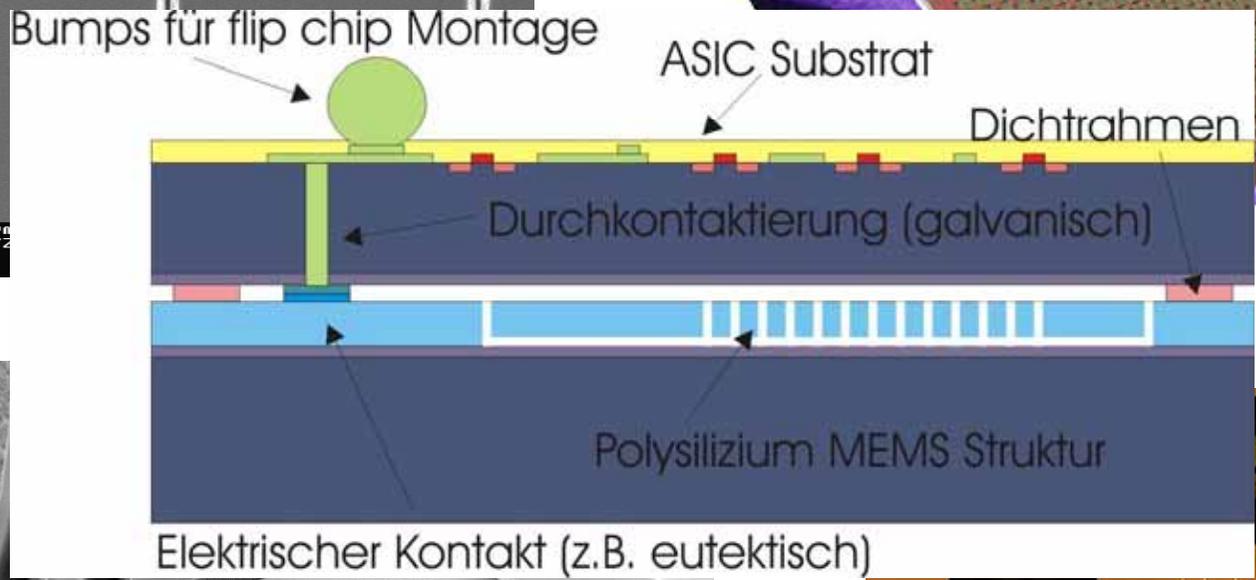
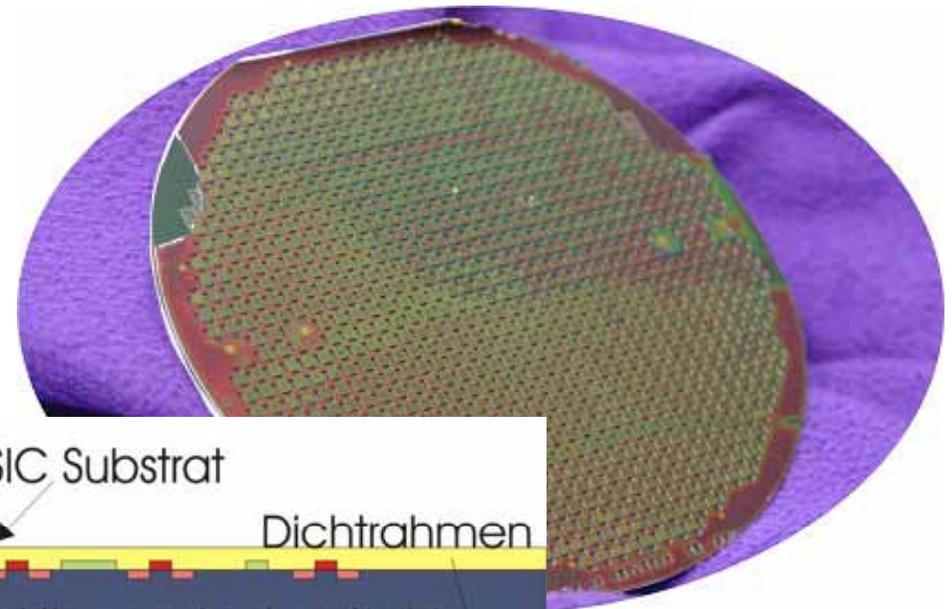
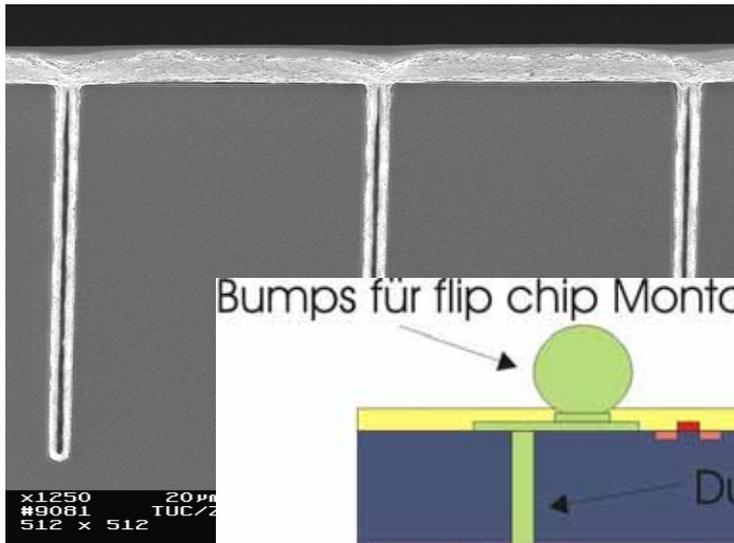
Interposer with sensor chip, RFID-chip and ASIC

Wafer bonding for and MEMS and electronics

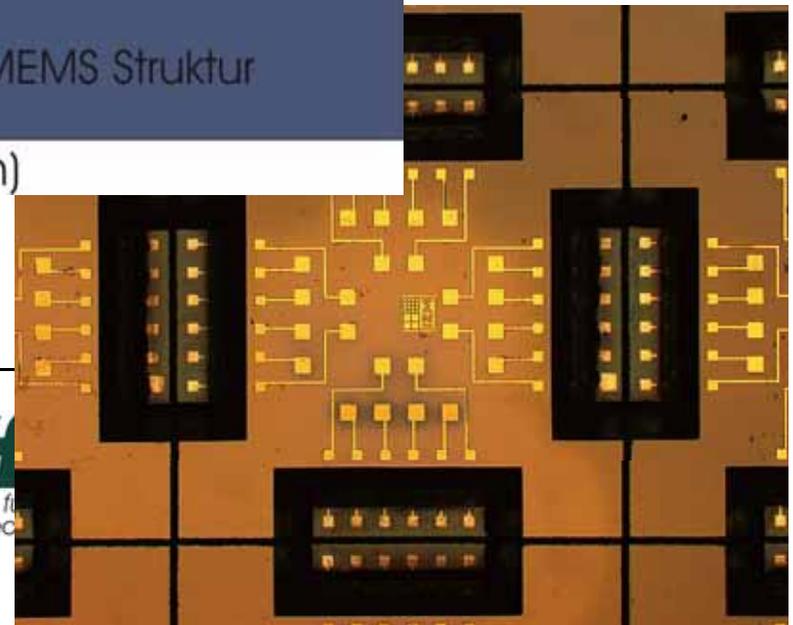


What is wafer bonding?
Wafer bonding techniques are used in microelectronics and micro mechanics to join thin, polished wafers made of different materials together - with or without additional intermediate layers.

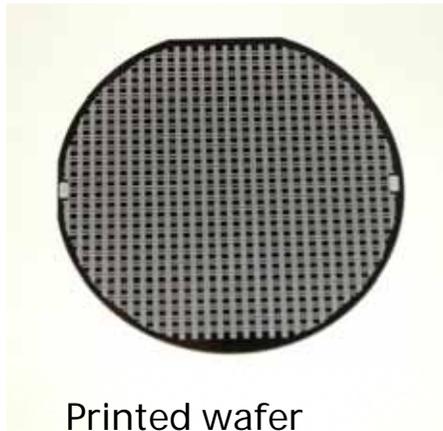
Wafer Level Packaging



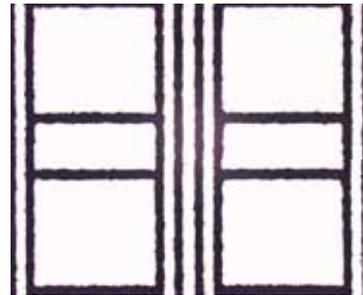
Z
Zentrum für
Mikrotec



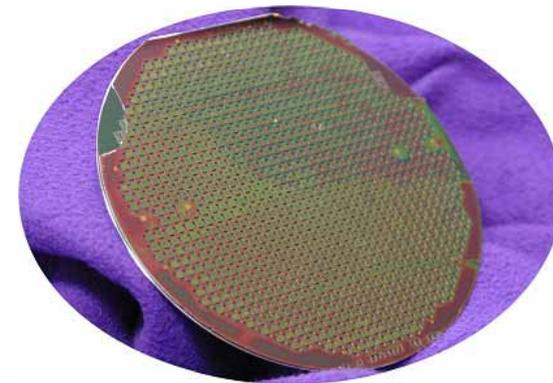
Packaging of vibration sensors



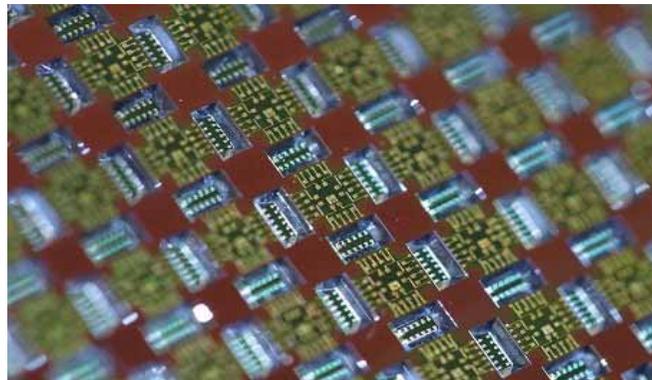
Printed wafer



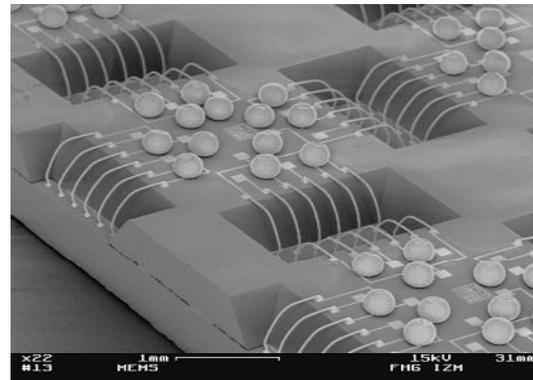
Printed Bond frame



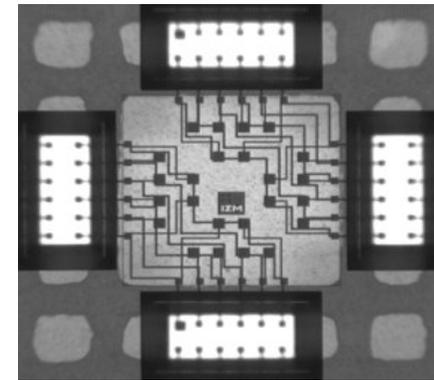
Bonded wafer



Top view of the cap wafer



MEMS-structure with redistribution



IR-image of bonded chips

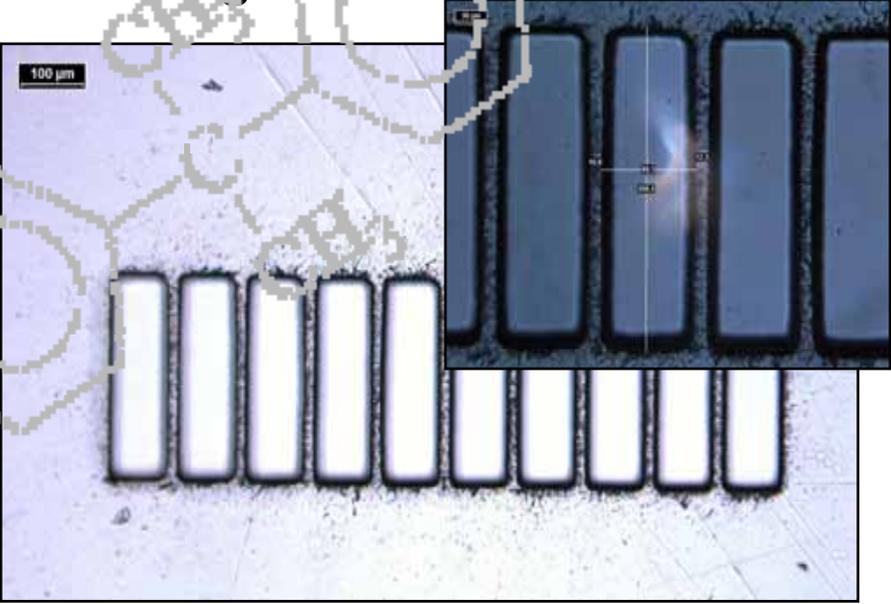
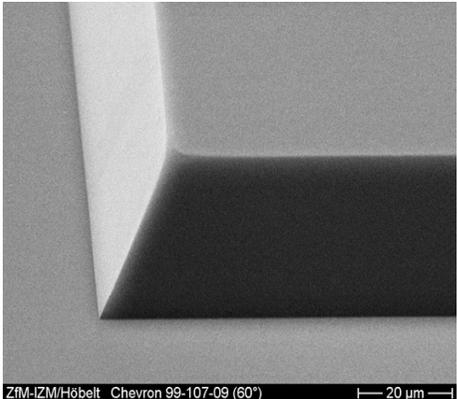
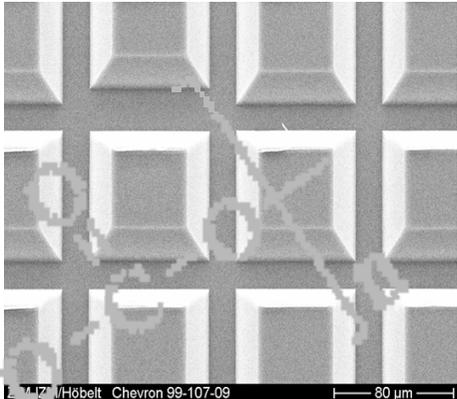
Non Silicon Technologies

Polymers

Hot Embossing 1

Bonding & Surfaces 2

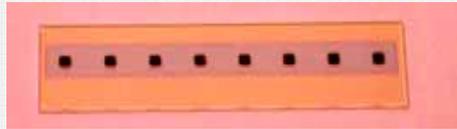
Laser structuring 3



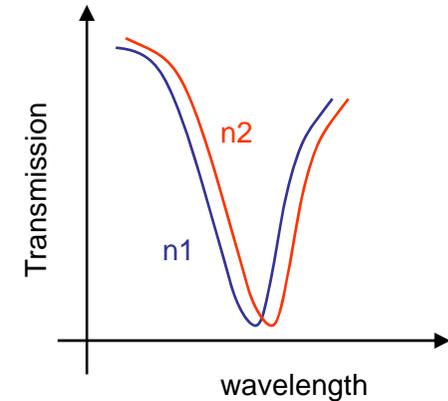
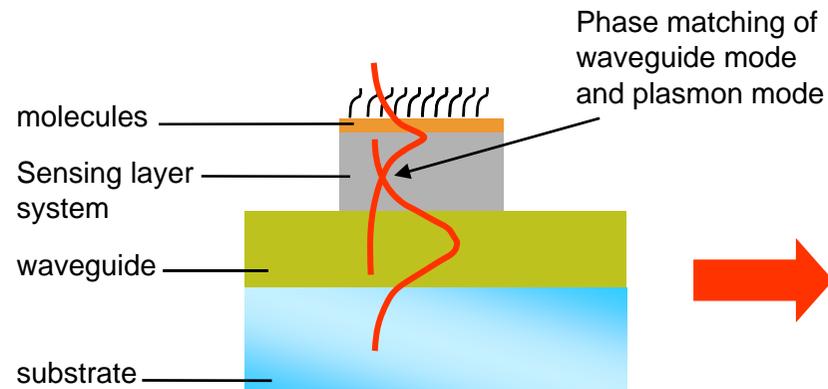
Bio sensing based on NEMS optical sensors

Sensing layer:

Multi layer stack based on Au or Ag, thickness < 150 nm



SPR sensor with waveguides:



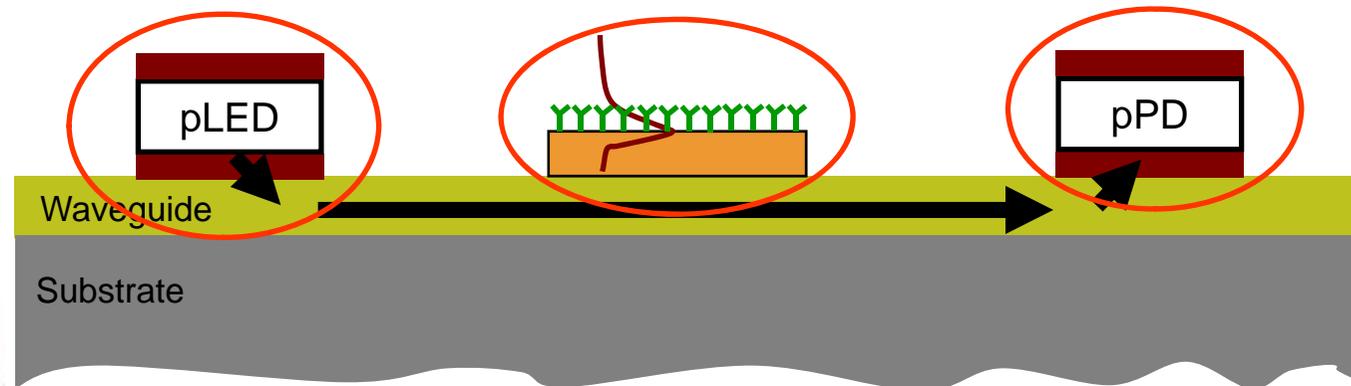
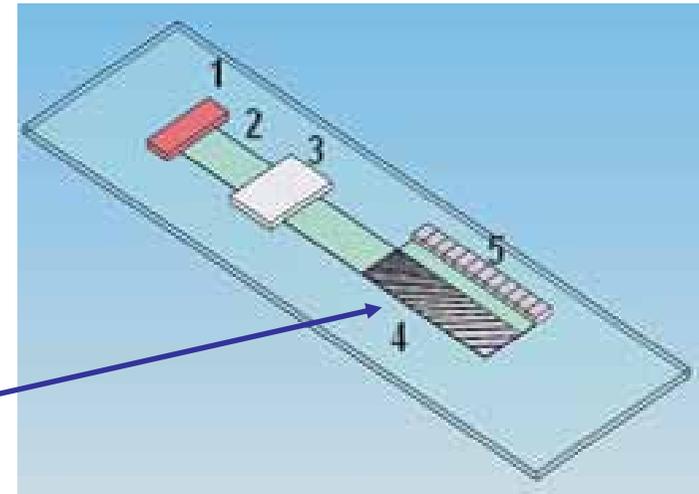
Sensing principle:

- Surface plasmon resonance at a metal-dielectric interface
- Interaction with mode guided in the waveguide
- Absorption peak depending on the refractive index
- Refractive index changes due to bio molecules attached to the surface



SPR waveguide coupling with integrated source and detectors

- High refractive index waveguides
→ high coupling efficiencies
- Organic LEDs and Photo Diodes
→ flat design for bendable substrates
- Plasmon Sensing Layer
- Chirped Grating Coupler
(for wavelength-selective outcoupling)



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Fraunhofer ENAS



Integration of optics and fluidics: The SEMOFS biocard

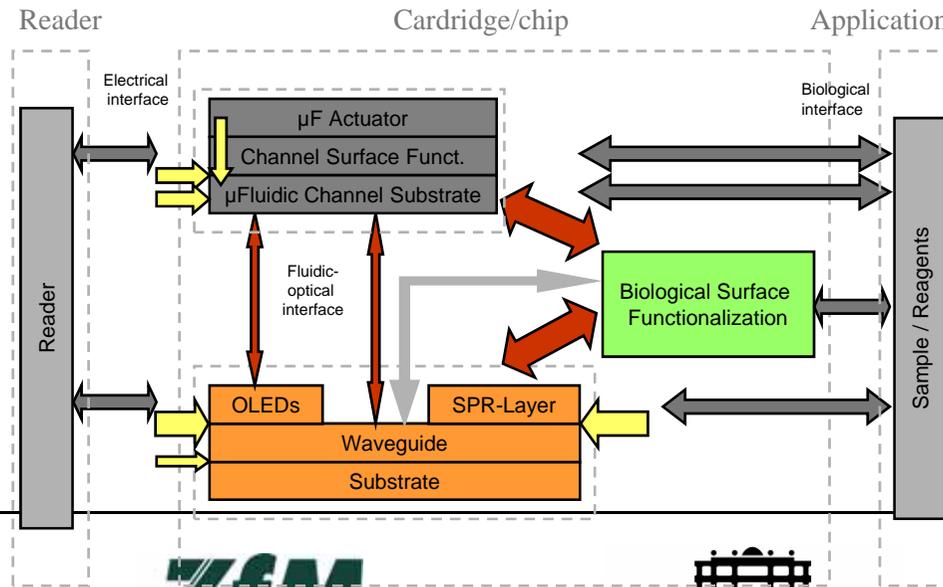
SEMOFS = Surface enhanced micro optical fluidic systems

Goal: fully integrated micro optics and micro fluidics (both active and passive) based on a polymer substrate for biosensing application

Partners: CSEM, CEA, ZEPTOSENS, EUROGENTEC, CHR cittadelle, Cardiff University, ALMA



Different functional parts and its interfaces of the fully integrated system:



OUTLINE

1. Introduction TUC/ZfM und Fraunhofer ENAS
2. MEMS und Smart Systems Integration
3. Examples from ZfM/ENAS
 - Micro mirrors
 - Spectrometer
 - Acceleration Sensors
 - RFID label
 - Wafer level and sensor packaging

4. Conclusion

Conclusions

- **The Fraunhofer Organization is a worldwide successful provider of research services**
- **Many products (prototypes) and technologies were developed and transferred in the field of Microelectronics and MEMS at the Fraunhofer ENAS**
- **Future trends are increasing functionality in one system at the same time with degreasing size and improved package**
- **Smart systems integration needs multi device integration by using different technologies as well as different materials**

Smart Systems Campus



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Fraunhofer ENAS



Fraunhofer ENAS Chemnitz



- ***New building Fraunhofer ENAS Chemnitz***
- ***Ground-breaking 5.11.2007***
- ***Finishing 05/2009***
- ***Topping-out ceremony 18.09.2008***

Faunhofer ENAS – A look behind the doors of new lithography clean room



Cluster for resist deposition (spin on and spray coating), exposure, develop and bake



European Conference & Exhibition on integration issues of miniaturized systems – MEMS MOEMS, ICs and electronic components

1. Conference : March 2007, Paris
2. Conference: April 2008, Barcelona
3. Conference: March 2009, Brussels

Organizer:



Fraunhofer



Einrichtung
Elektronische
Nanosysteme

Part of the
activities
of:



EPoSS

European Technology Platform
on Smart Systems Integration



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Fraunhofer ENAS

Fraunhofer



Einrichtung
Elektronische
Nanosysteme

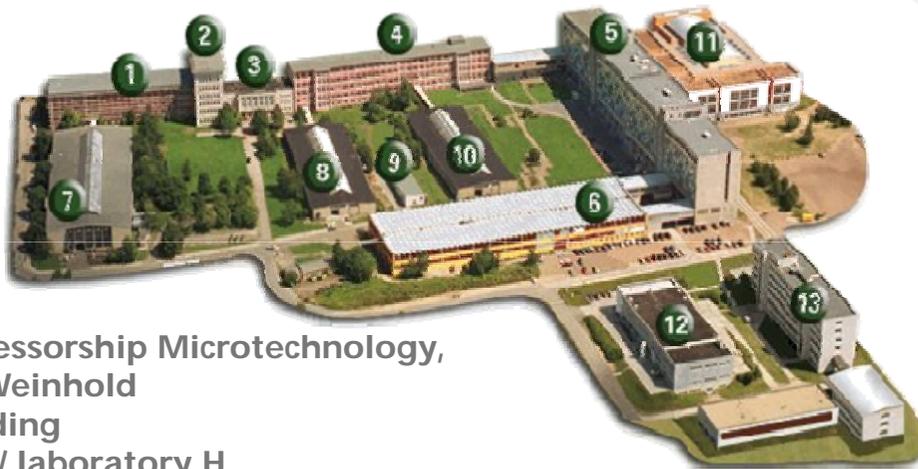
ZfM
Zentrum für
Mikrotechnologien



TECHNISCHE UNIVERSITÄT
CHEMNITZ

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<http://www.enas.fraunhofer.de>



- 5 Professorship Microtechnology, Weinhold building
- 6 ZfM / laboratory H
- 12 Fraunhofer building with ENAS labs



Characteristics of Smart Systems Integration

MULTIFUNCTIONALITY

→ Multi Device Integration

MULTITECHNOLOGY

→ Combination of different technology approaches

MULTIMATERIALS

→ Combination and integration of advanced materials

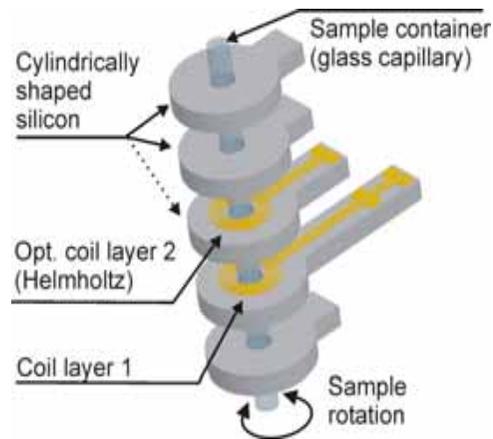
SSI

- Improved Functionality and Performance
- New Components or Sub-Systems

New approaches required concerning:

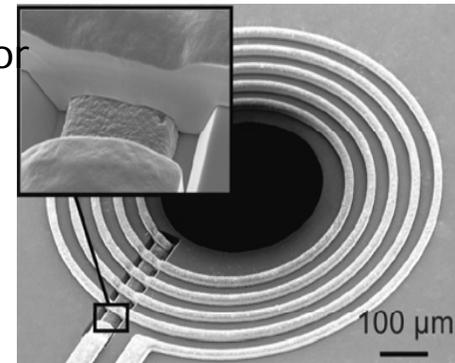
- System / Component design
- Reliability aspects
- Usage of huge effective technologies

NMR Microcoil for Biological Samples in nL-Volumes



Schematic drawing of NMR detector

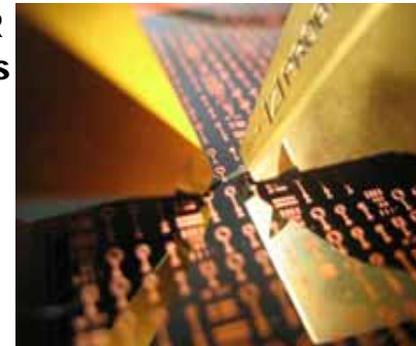
- Project Title: „NMR Micro Resonators for Metabolic Profiling of Hematopoietic Stem Cells“
- Project agency: EFRE (SMWK), Project duration: 07/05-06/07



High Q factor NMR microcoil

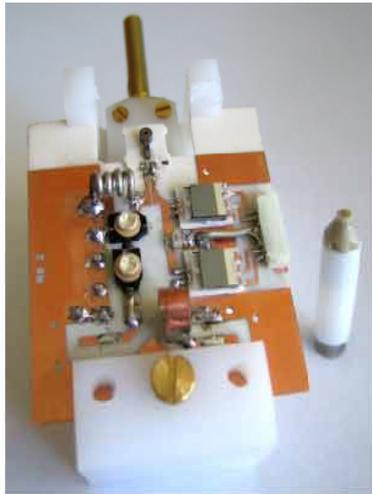


Photography of NMR detector components

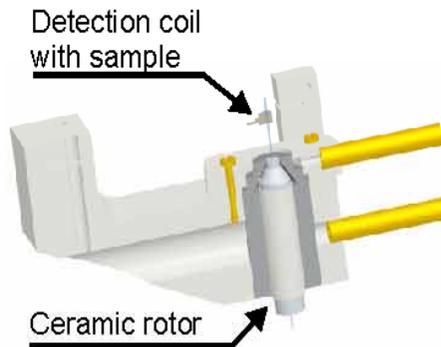


On wafer test of microcoils

Miniaturized NMR Analysis System



Photograph of the assembled measurement system



Schematic drawing of pneumatic sample rotation (partial cross-section, details on flow channels omitted)



Positioning of detection coil at the "magnetic center" (maximal field strength and highest field homogeneity)

NMR Spectrometer



Bruker Avance 750 cryogenic magnet ($B_0=17.6\text{ T}$)



Stem cell culture (1.000-10.000 cells)

Identification of characteristic patterns yield information on the chemical composition and therewith information on how metabolics are integrated in cell structure (metabolic pathway)

